

The influence of the external temperature on a cooling box thermoelectric system

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Abstract

In the present paper, a thermoelectric cooling system modelling of a box was developed and the influence of the external temperature on this system was analyzed. The modelling shows that high external temperatures limit the thermoelectric cooling performance of the system. It was observed also that the external temperature limit the value of heat that can be removed by the thermoelectric system for each internal temperature set point of the cooling box. Substitute the thermoelectric cooling module (TEC) is an option to improve the cooling performance, however is important to observe that the external temperature can affect this improvement.

Keywords: Thermoelectric; Cooling; TEC; External temperature

INTRODUCTION

Thermoelectric is a physical phenomenon that involves the interaction between electrical and thermal energy between semiconducting materials (Lundgaard and Sigmund, 2019). Thermoelectric cooling modules (TEC) converts electrical energy in thermal energy by the Peltier effect. This effect is achieved in these devices when a voltage is applied to their semiconductors which provides heating on one side of the module and cooling on the other side.

Thermoelectric cooling has different advantages than other refrigeration systems as high reliability, no mechanical moving parts, compact size and lightweight, and no working fluid and some disadvantages like lower energy efficiency and higher cost (Zhao and Tan, 2014). Cooling thermoelectric systems are generally used in applications where the advantages of these systems are needed. Thermoelectric refrigeration is found in electronic and automobile cooling systems, photovoltaic-thermoelectric hybrid cooling system, thermoelectric air-conditioning, among others (Mirmanto, et al., 2019).

Electrical current is an important parameter that affects the performance of the thermoelectric cooler module (TEC) (Eslami et al., 2018). The maximum electrical current is the electrical current in which occurs the highest heat remove by thermoelectric module, so that current can distinct the TEC by the cooling capacity. In general, TEC with higher maximum existing can provides higher heat removed in the thermoelectrical system.

For cooling boxes, the external temperature (T_{ext}) is an essential parameter to the performance of the thermoelectric cooling system because this temperature can limit the cooling effect. In the present paper a cooling box thermoelectric system modelling was elaborated and the effect of the external temperature in its performance was analyzed.

MODELING OF THE SINGLE-EFFECT ABSORPTION CHILLER

The thermoelectric cooling system in the modelling consists of a cooling box cooled by a thermoelectric cooling module (TEC) coupled with fan and heat sink in each side. Figs. 1 and 2 represent the thermodynamic cooling system analyzed.

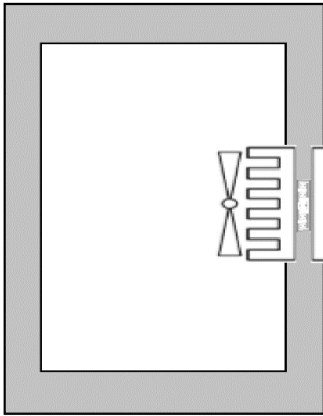


Figure 1: Thermoelectric cooling box.

In this cooling box, a thermoelectric cooling module (TEC) is coupled in each side with two fan/heatsink. Fig. 2 shows these components.

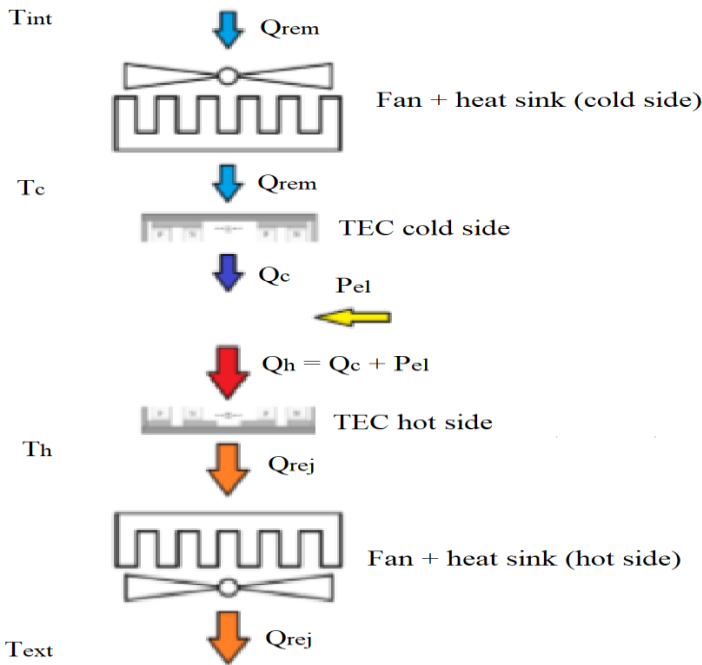


Figure 2: Thermoelectric cooling module (TEC) and the coupled fan/heatsinks.

Considering the steady-state condition, the principal equation from the energy balance are:

- $Q_{rem} = (T_{int} - T_c) / \theta_{tc}$ (1)
- $Q_{rem} = Q_c$ (2)
- $Q_c = (\alpha \cdot I \cdot T_c) - (0,5 R \cdot I^2) - [K \cdot (T_h - T_c)]$ (3)
- $Q_{rej} = (T_h - T_{ext}) / \theta_{th}$ (4)
- $Q_{rej} = Q_h$ (5)
- $Q_h = (\alpha \cdot I \cdot T_h) + (0,5 R \cdot I^2) - [K \cdot (T_h - T_c)]$ (6)
- $Q_h = Q_c + P_{el}$ (7)
- $P_{el} = I \cdot V$ (8)
- The coefficient of performance (COP) is expressed in the equation 9:
- $COP = Q_c / P_{el}$ (9)

where:

- Q_{rem} : heat removed by the fan/heat sink [W];
- Q_c : heat removed by the TEC cold side [W];
- Q_{rej} : heat rejected by the fan/heatsink [W];

Qh: heat rejected by the TEC hot side [W];
 Pel: electrical power [W];
 V: voltage [V];
 I: electrical current [A];
 R: electrical resistance [ohm];
 α : Seebeck coefficient [V/K];
 Θ_{tc} : thermal resistance of the cold side [$^{\circ}\text{C}/\text{W}$];
 T_c : TEC cold side temperature;
 T_{int} : cooling box internal temperature;
 Θ_{th} : thermal resistance of the hot side [$^{\circ}\text{C}/\text{W}$];
 T_h : TEC hot side temperature;
 T_{ext} : cooling box external temperature.

The equation from the thermodynamic model was programmed in computational software. The Seebeck coefficient, the electrical resistance and the thermal conductance from the TEC were obtained by Ferrotec. The TEC adopted was a Ferrotec 9500/127/060 B module that has 6A of maximum current. In the cold side of the thermoelectric module is coupled a fan/heat sink with thermal resistance value of 0,7 $^{\circ}\text{C}/\text{W}$ and in the hot side of the thermoelectric module is coupled a fan/heat sink with thermal resistance value of 0,2 $^{\circ}\text{C}/\text{W}$.

The input data range of the cooling box internal temperature (T_{int}) is from 0 $^{\circ}\text{C}$ to 10 $^{\circ}\text{C}$. Considering 12 V input voltage, the other parameters were found in the modelling. Then the modelling equations were calculated and graphs with different heat removed and external temperature conditions were plotted and analyzed to understand the impact of this temperature in this thermoelectric cooling system.

RESULTS AND DISCUSSION

Fig. 3 shows for different values of heat removed what is the external temperature that the internal temperature of the cooling box is reached with the rated voltage.

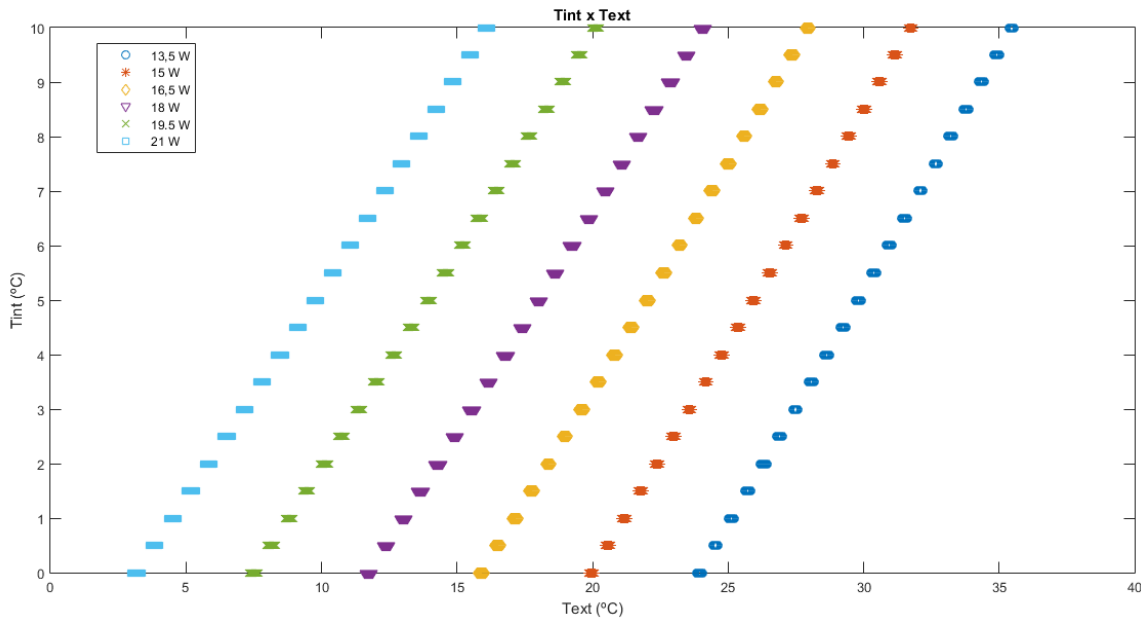


Figure 3: Internal temperature of the box (T_{int}) versus external temperature (T_{ext}).

In the graph of Fig. 3 it can be seen that the heat removed from the cooling box by this thermoelectric cooling system is limited by the external temperature. In a certain external temperature, the higher is the heat to be removed, the less cold the internal temperature is obtained. Observing in another way, a certain internal temperature desired in the cooling box in a high external temperature can be reached only with a lower heat removed. This occurs due the higher external temperatures limit the dissipation of the heat rejected from the thermoelectric module.

In the Fig. 4 is the graph of internal temperature (T_{int}) versus the temperature of the thermoelectric module (TEC) cold side (T_c).

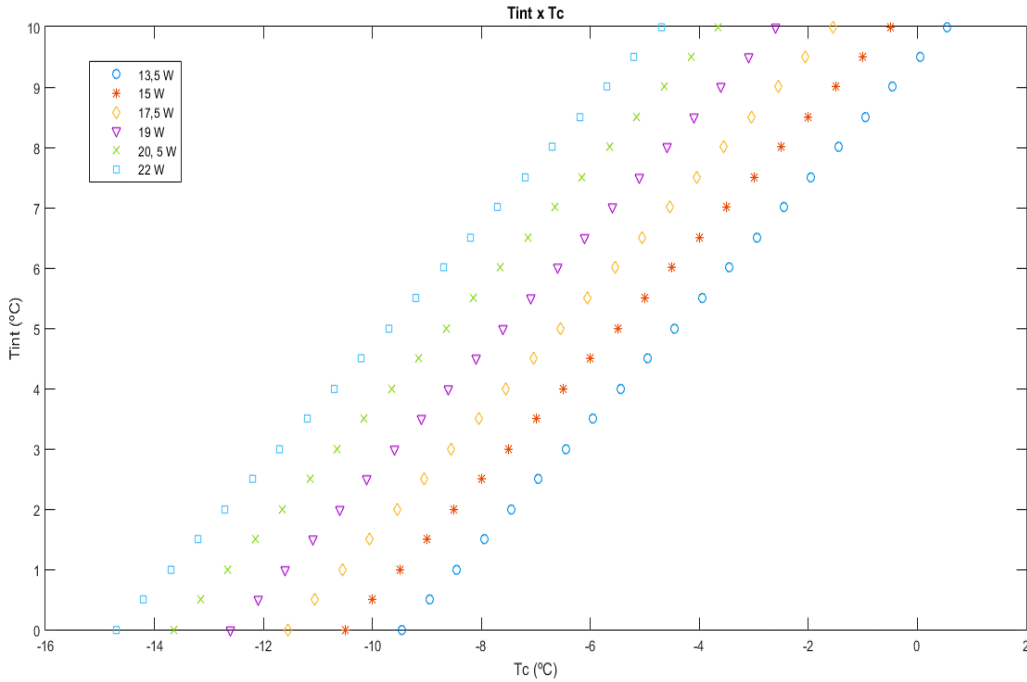


Figure 4: Internal temperature (Tint) versus TEC cold side temperature (Tc).

The graph of Fig. 4 shows the Tc temperature necessary do attain a setpoint temperature in the cooling box for different values of heat removed. High heat to be removed implies the lower Tc required to obtain the set point cooling box temperature (Tint). In other words, for a certain temperature of the TEC cold side (Tc), the lower is the heat removed (Qrem), the lower is the Tint obtained. This is consequence of equation 1 which shows that Qrem subtracts the Tc value in its expression.

It was observed in the graphs of Figs. 3 and 4 that for this thermoelectric cooling system the internal temperature of the cooling box (Tint) is limited by its the external temperature (Text). A possibility to improve this thermoelectric cooling system substitutes the thermoelectric module to another with higher capacity. In general, thermoelectric modules obtain higher heat removed when its current is higher for the same voltage. The TEC specification normally shows the maximum current (Imax) that achieve the higher heat removed by the thermoelectric cooling module. Thereby, TEC with different Imax has different performance to reach a certain set point temperature in the cooling box.

The graphs plotted in Figs. 5, 6 and 7 show the values of heat removed from the cooling box in different external temperatures for each TEC module. Each graph is for a distinct cooling box internal temperature (Tint).

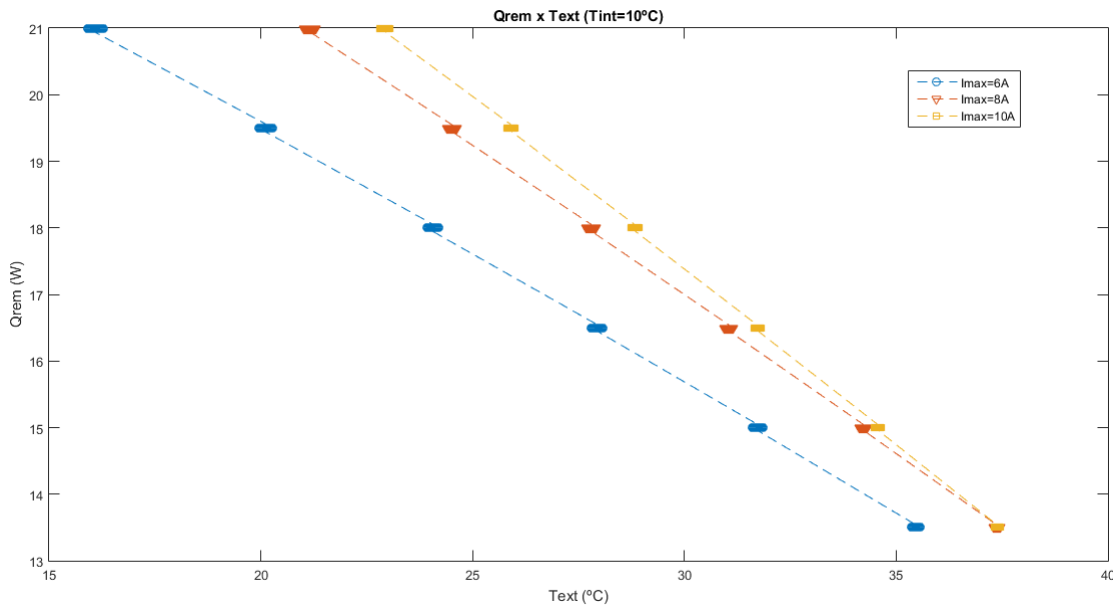


Figure 5: Heat removed (Qrem) versus Text (Tint = 10 °C).

From the graph of Fig. 5 it can be observed that the thermoelectric cooling system can remove the same value of heat in higher external temperature (Text) with TEC that have higher Imax. It could be seen also that for a specific external temperature (Text), TEC with higher Imax, achieve higher heat removed (Qrem).

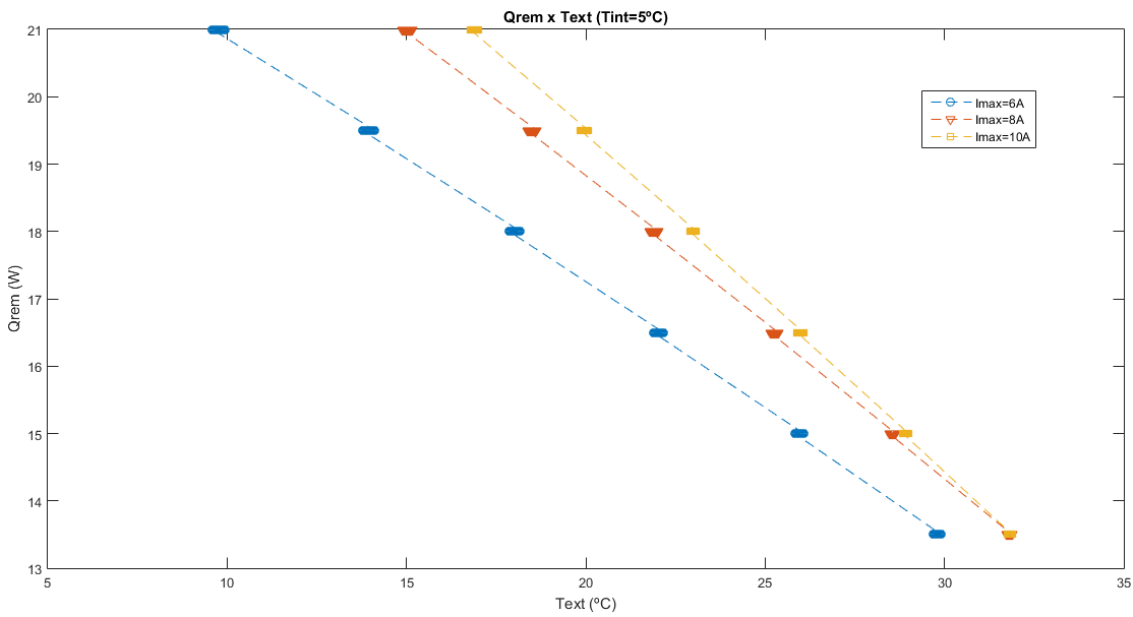


Figure 6: Heat removed (Qrem) versus Text (Tint = 5 °C).

The graph of Fig. 6 has the same behaviour of the graph seen in Fig. 3, however each value of heat removed is obtained with lower external temperature (Text) than the graph of Fig. 3. When it needs a lower set point cooling box temperature (Tint) for the same external temperature (Text) and the same heat removed, the TEC changing sometimes is not sufficient. This can be observed especially in high values of Text where the difference of the heat removed by the different TEC is lower.

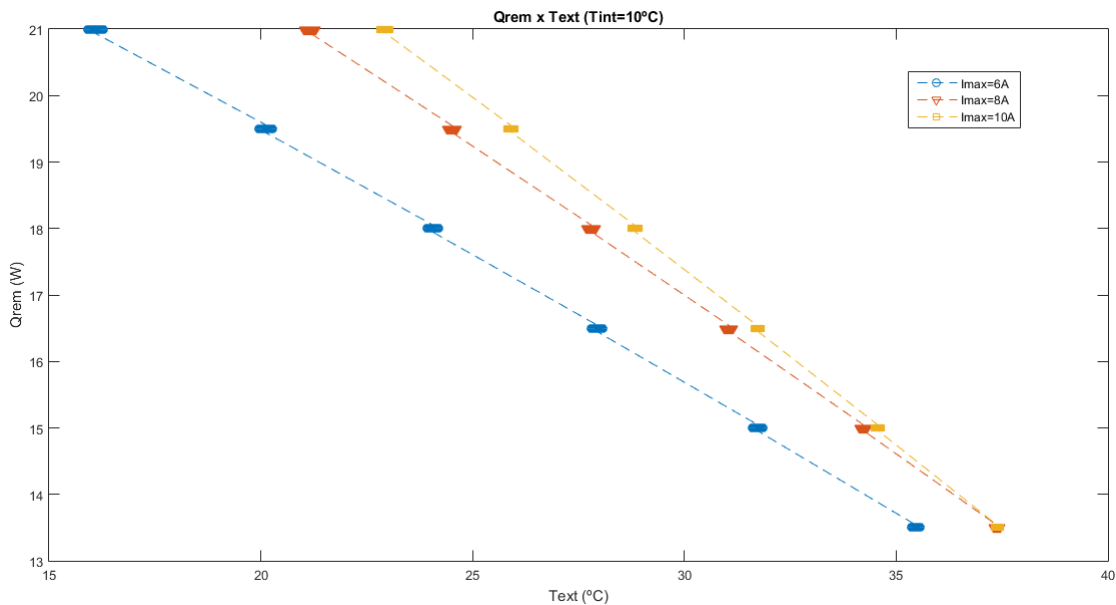


Figure 7: Heat removed (Qrem) versus Text (Tint = 0 °C).

The graph in Fig. 7 presents the same behavior of higher heat removed (Qrem) by TEC with higher Imax at the same external temperature and this difference increases for lower values of Text. This probably occurs due to the fact that to achieve a lower temperature in the cooling box (Tint) demands more heat rejected in the TEC hot side and sometimes the external temperature limits the dissipation of this heat. For 0°C value of Tint, for thermoelectric system reach the same heat removed (Qrem) at same Text value and 10 °C value of Tint is not more possible as can be seen comparing the graphs of the Figs. 5 and 7.

CONCLUSION

The results of the thermodynamic model elaborated of the thermoelectric system showed that the external temperature (T_{ext}) limited the cooling performance. Higher external (T_{ext}) temperatures imply in lower cooling capacity and less cold internal temperatures (T_{int}) are reached.

Changing the thermoelectric cooling module (TEC) is a possible solution to improve the cooling effect. However is important to check if the external temperature doesn't limit the internal temperature (T_{int}) set point of the cooling box.

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