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EXPERIMENTAL HEAT DISSIPATION ON THERMOELECTRIC PLATES FOR CLINICAL APPLICATION IN COOL CAP

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Abstract. *In this work, an experimental study of the heat dissipation of thermoelectric plate has been done with the focus on the cool cap. The cool cap is a device used in localized hypothermia for newborns with perinatal asphyxia, because the sequelae in the brain can decrease due to the reduction of brain temperature. An interesting alternative in order to decrease the size of cool cap is the use of thermoelectric plates. However, an efficient dissipation of heat should be considered for the hot side of thermoelectric plates, because the thermoelectric plates can be considered as a thermal pump, which transfer the heat from the cold side to the hot side. Three configurations for heat dissipation were experimentally tested. The first was a flat plate of aluminum, which was assembled on the hot side of a thermoelectric plate. The second was a finned surface of aluminum. The last was the same of second, however, two thermoelectric plates were used in cascade. The three configurations were tested with and without heat sink paste between the dissipator and the thermoelectric plates. The temperature of the environment and both hot and cold sides were measured with LM35 sensor and an Arduino in different levels of activation for each configuration. The results have shown that the dissipators with finned surfaces and heat sink paste were more efficient. The possible use of forced convection by means of compact fans has also been considered, because the performance of finned surfaces still requires an improvement. For a proper application of cool cap, the temperature on the scalp of newborns should be around 16º C.*

Keywords: *cool cap,thermoelectric plates,heat dissipation,dissipators*

1. INTRODUCTION

The Cool Cap is a device for clinical applications, which is used for localized hypothermia in newborns with perinatal asphyxia. The main aim of this device is the minimization of the sequels due to the absence of oxygen in the brain. This aim is reached by the decrease of the metabolic activity by means of the localized cooling.

Hypoxia Ischemic Encephalopathic (HIE) is a major cause of permanent neurological damage in newborns (Guinsburg *et al.*, 2008) with perinatal asphyxia. In accord to Prakesh (2010), Thoresen (2011), Fairchild *et al.* (2010) and Baird (2010), hypothermic treatment started within 6 hours after asphyxia could be an effective form of treatment.

Rutherford et al. (2005) have compared HIE treatments with and without body cooling (total and partial, respectively) and they have noticed that brain injuries of children that were treated with cooling were lower than those without treatment. These reductions in the amount of injuries were achieved at the incidence of moderate HIE and smaller with severe HIE, and newborns with severe HIE and treated with cranial cooling showed greater reduction.

The conventional cool caps commercially available are comprised by a reservoir of fluid, cooled by a refrigerator unit, and this fluid recirculates in a system of tubes around the head of newborns. Thus, the temperature on the head can be decreased until the target temperature for localized hypothermia is reached. The main disadvantage of the conventional cool cap is the size. The size plays an important role in cases of emergency, since the system cannot be installed in a delivery room due to the space. Also, the absence of the cool cap in a hospital will require the transportation of the patient to another center with this type of equipment.

In order to reduce the size of cool cap, an alternative would be the use of thermoelectric cold plates. The thermoelectric cold plates based on the Peltier effect are devices that generate a flow of heat between two surfaces. Usually, the surfaces are called as hot side and cold side. This phenomenon was discovered by Peltier in 1834 (Yang *et*

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al., 2013). The use of these plates has increased in the decade of 1960 due to the advanced development of semiconductors materials with ceramic substrates.

The thermoelectric cold plates are comprised by several thermocouples that are connected thermally in parallel, and electrically in series. The thermocouples are formed by pairs of material of n-type and p-type (Pérez-Aparicio *et al.*, 2011). This plate works through by a movement of electrons in the thermocouples. In the cold side, the heat is absorbed by electrons as they move from a low level of energy in the semiconductor type-p to a higher level of energy in the semiconductor type-n. The electrical source provides energy to move the electrons inside the system. At the hot side, the energy is released by convection to the environment; hence, the electrons will pass from the high level of energy of the semiconductor type-n to a lower level of energy in the semiconductor type-p (Laird Technologies, 2010). In other words, the thermoelectric plates are similar to thermal solid pumps, that is, they transfer heat without any fluid (Laird Technologies, 2010).

A limitation of these plates is related to the dissipation of heat from the hot side. In other words, the performance depends on the dissipation of heat in order to improve the flow of heat, which it will decrease the temperature of the cold side. For the cool cap, the temperature in the brain for a clinical application in perinatal asphyxia is around 34.4 to 35 ºC (Battin *et al.*, 2003). In a previous work (Barrios *et al.*, 2010), the temperature on the scalp of the newborn was calculated to be around 32 ºC for a temperature of 34.4 ºC in the brain. For that work, the authors had used an adaptation of the model proposed by Sukstanskii *et al.* (2004). Based on these results, it is possible to notice the importance of a efficient performance of the peltier plates for this application.

Albeit the temperature of 32 ºC is not too high, it is necessary to consider the metabolic reaction of the human body, which works in order to keep the temperature at around 36.5 ºC. For the conventional cool caps, the temperature of the fluid is in a range between 8 to 12 ºC, in order to obtain a retal temperature of 34.5 ºC (Gluckman *et al.*, 2005). In order to reach these temperatures, the improvement of the heat dissipation on the hot side of peltier plate is very important for a successful clinical application.

Thus, in this work, a experimental study of heat dissipation of peltier plates for a cool cap was done. The concept and project of this cool cap has been reported in a previous work (Naka *et al.*, 2011). The improvement of the heat dissipation is crucial for the cool cap. Furthermore, the restrictions due to the weight of the device and also the confort have been considered for the study of heat dissipators for this cool cap.

2. MATERIALS AND METHODS

2.1 Materials

Thermoelectric cold plates were provided by Acel (model TEC112706) with a maximum voltage of 15.4 V and a maximum electrical current of 6 A. The quantity of pairs of thermocouples was 127 and the maximum thermal power was of 51.4 W. The format of the plates was a square with 40 mm of side and a thickness of 3.8 mm. In Fig. 1, it is shown a picture of the peltier plates used in the tests.

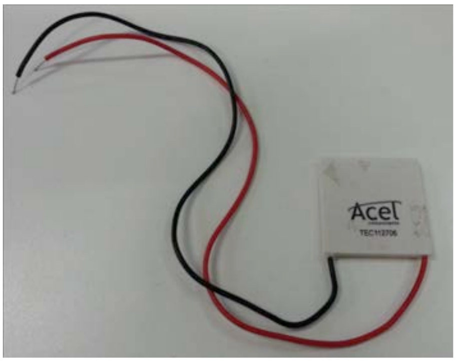

Figure 1. Peltier plate from Acel.

Heat dissipators used in this work were shown in Fig. 2. For this work, three heat dissipation systems have been tested and they will be described in the next sub section, Methods. The dissipators with finned surface were obtained from computer hardwares and the flat surface was fabricated in the Metal-Mechanical Laboratory of UCDB. For the third configuration using a Peltier cascade, a holder was also fabricated at the same laboratory.

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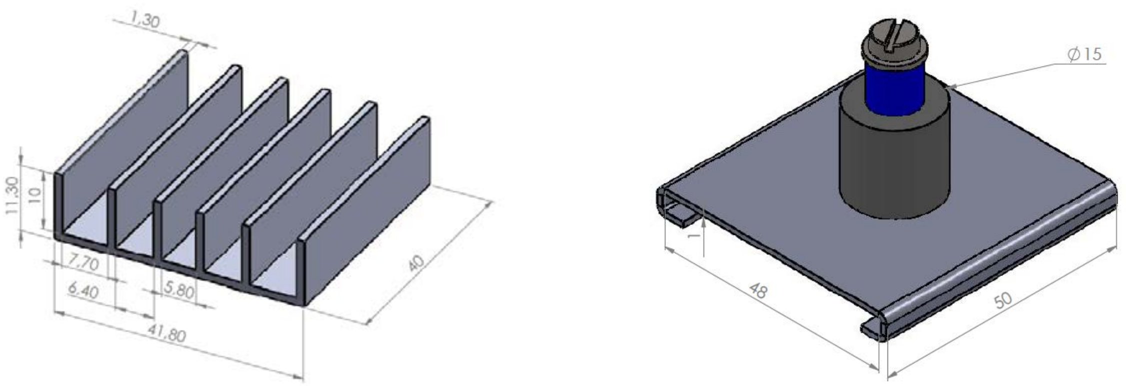

Figure 2. Heat dissipators. At left, a finned surface dissipator and at right, a flat aluminum plate dissipator.

A heat sink paste was also used in the tests, in order to improve the contact between the hot side of peltier plates and the heat dissipators. This paste has a base of silicon polymers and was provided by Implastec. The thermal conductivity of the paste was 0.4 W/mK, in accord to ISO 8301:1991.

2.2 Methods

The tests were carried out in a room with a controlled temperature of 24 ± 1 ºC. The effects of heat transfer were associated only with the natural convection and radiation between the environment and the hot side of the peltier plates.

In other words, no forced convection system has been used and tested in this work. The data was obtained from 3 integrated circuits (LM35) that were used as temperature sensors. The sensors have been positioned on the each side of the peltier plate, that is, one on the hot side and another on the cold side. The third sensor was used to measure the room temperature. The arrangement of the sensor can be viewed in Fig. 3, for the test with finned surfaces.

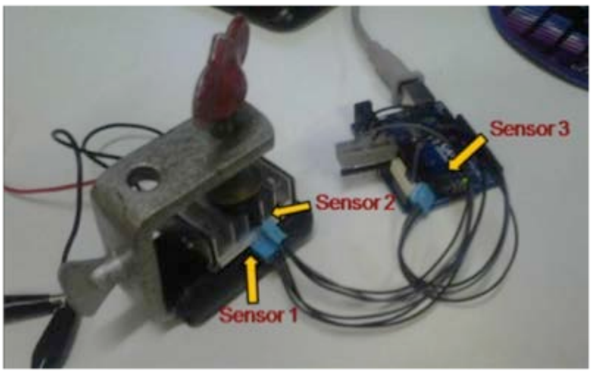

Figure 3. Arrangement of sensors for the temperature tests. The sensor 1 is placed on the cold side, the sensor 2 on the hot side and the sensor 3 was used for the measurement of environmental temperature.

The sensors have been connected to a microcontroller Arduino ®, that was responsible to acquire the analogic signal from the sensors and to convert the signal to the digital format, using a proper algorithm. The data in digital format were saved in a format txt, which would be analyzed using Excel ® worksheets.

Three different configuration of heat dissipation have been tested in this work. The first system is the most simple and consists of a aluminum plate placed on the hot side of peltier plate, as can be viewed in Fig. 4.a. The second system (Fig. 4.b) consists of a finned surface placed on the hot side and the last (Fig. 4.c) consists of a two peltier plate arranged in cascade. In the last configuration, the cold side of a peltier plate was placed on the hot side of another peltier plate, that is, the first plate works as a dissipator. Also, for this last configuration, a finned surface has been used in the hot side of the peltier plate on the top.

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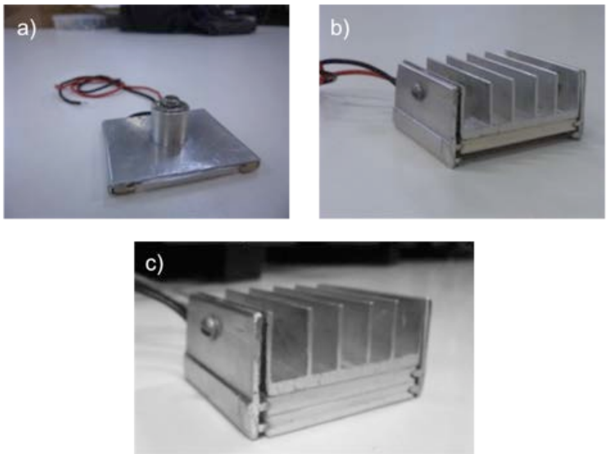

Figure 4. Configuration for the heat dissipation tests. a) aluminum flat plate, b) finned surface and c) peltiers in cascade.

For each configuration of heat dissipation system, three tests have been carried out at different levels of voltage. The data were evaluated in three different ways in relation to the time: the difference between the temperatures of cold side and environment ($\Delta T_{env-cold}$), the difference between the temperatures of hot side and environment ($\Delta T_{hot-env}$) and at last, the difference between the temperatures of hot and cold sides ($\Delta T_{hot-cold}$). For the hot side, the sensor was positioned on the dissipation plate. Also, two modes of coupling between the thermoelectric plates and the dissipators have been used: with and without heat sink paste. These tests were done in order to evaluate the role of the coupling between the dissipators and peltier plates.

For the first configuration with a flat plate of aluminum, three different voltages had been applied and for each case (1 V, 1.5 V and 2 V), the test were carried out with and without thermal sink paste between the peltier plates and heat dissipators. For second configuration with finned surface, the tests were under the same conditions as the previous with a flat plate of aluminum. In the last configuration, the voltages applied on the peltier plates were the same as before, but a measurement at 3 V was also done. The tests were carried out during 300 s and with a sampling rate of 0.1 Hz. In Fig. 5, it is shown the whole system used for the experimental tests.

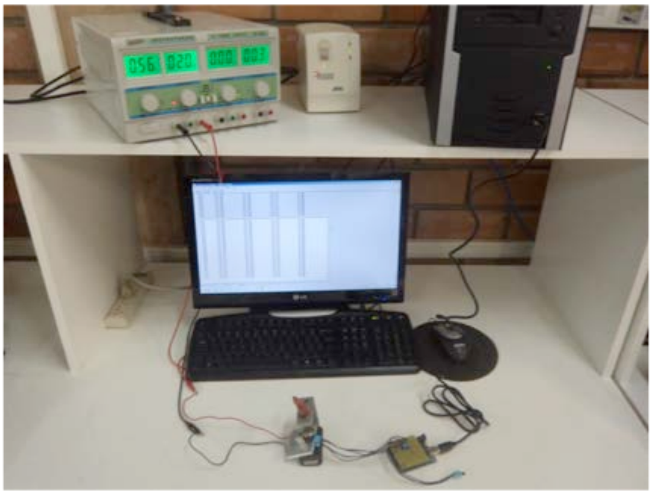

Figure 5. The system developed for the tests with peltier plates and the heat dissipators.

3. RESULTS

In Figures 6 to 8, the results for the flat plate of aluminum as dissipator has been presented. In Fig. 6, it is shown the results between the difference of the cold side and the environment temperature. The difference between these temperatures has been considered because the environmental temperature has a strong influence in the performance of peltier plates and hence, also in the temperature of cold side, as mentioned before in the section of Introduction. In Fig. 7, it is shown the results of the difference of temperature between the hot and cold side and at last, in Fig. 8, the results of the difference of temperature between the hot side and environmental temperature.

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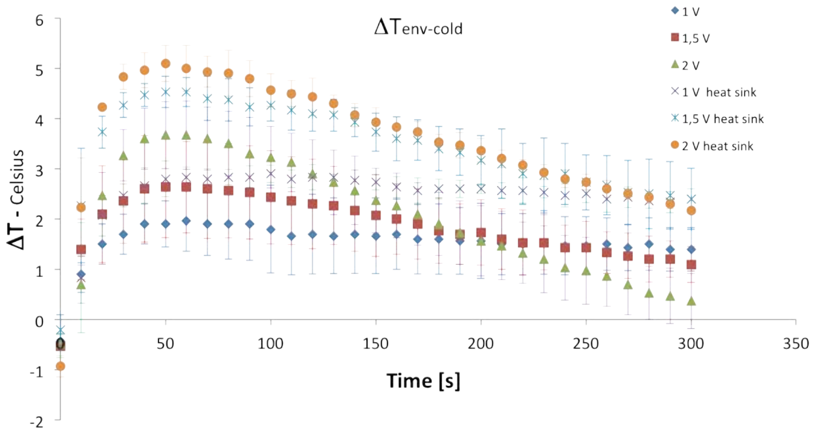

Figure 6. Difference of temperatures between the environment and cold side in relation to the time, for the aluminum flat plate dissipator.

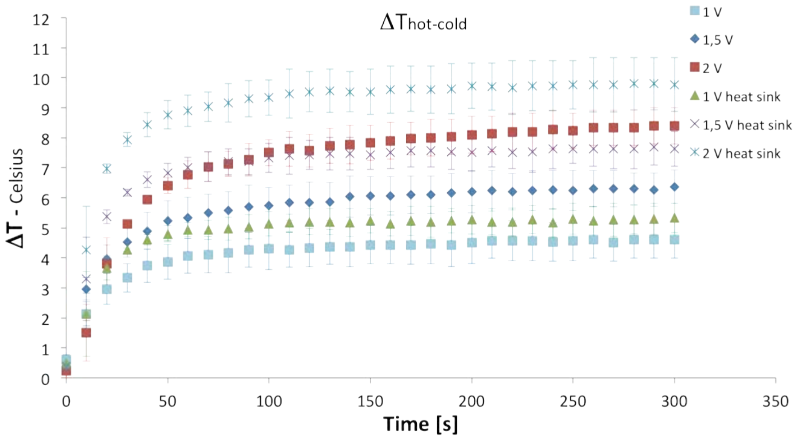

Figure 7. Difference of temperature between hot and cold sides in relation to the time, for the aluminum flat plate dissipator.

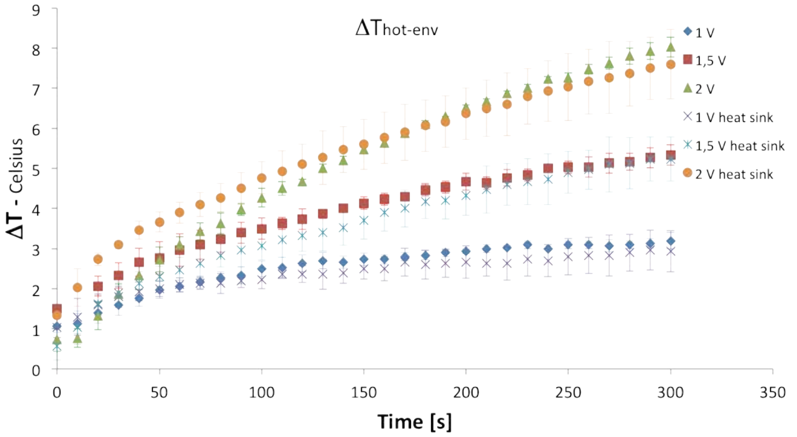

Figure 8. Difference of temperatures between the environment and hot side in relation to the time, for the aluminum flat plate dissipator.

In Figs. 9 to 11, the results for the finned surface dissipator have been presented. The trends of the curves are similar to the aluminum flat plate dissipator, in all cases. As can be also observed for the flat plate, the results with heat sink is better in terms of performance, that is, the cold side has been cooled at lower temperatures in comparison to the cases without heat sink. Albeit the stability of the difference of temperatures between the hot and cold side can be observed in the beginning of the test, the other tests (difference between the environmental temperature) they do not show a strong stability during the test.

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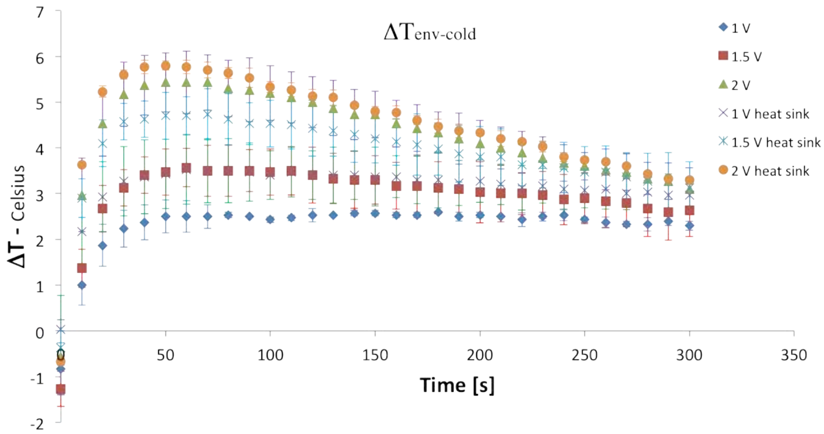

Figure 9. Difference of temperatures between the environment and cold side in relation to the time, for the finned surface dissipator.

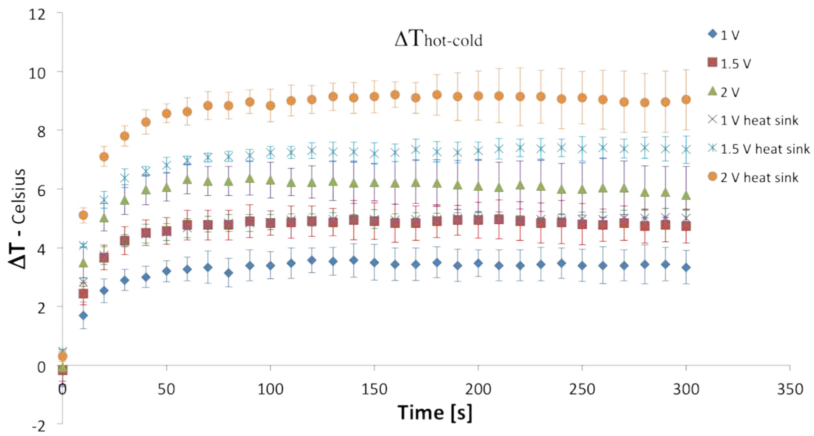

Figure 10. Difference of temperatures between hot and cold sides in relation to the time, for the finned surface dissipator.

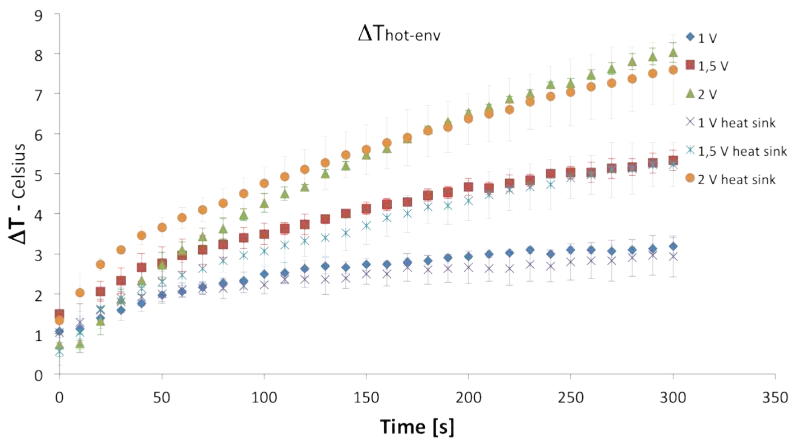

Figure 11. Difference of temperatures between the environment and hot side in relation to the time, for the finned surface dissipator.

In Figs. 12 to 14, the results for the peltier plates in cascade are presented. In all the curves, it is possible to observe a best performance in comparison to the other tests. However, the stability between the hot and cold side takes more time to be reached in comparison to the previous tests. On the other hand, a stability of the difference of temperature between the cold side and the temperature of environment can be observed after about 150 s.

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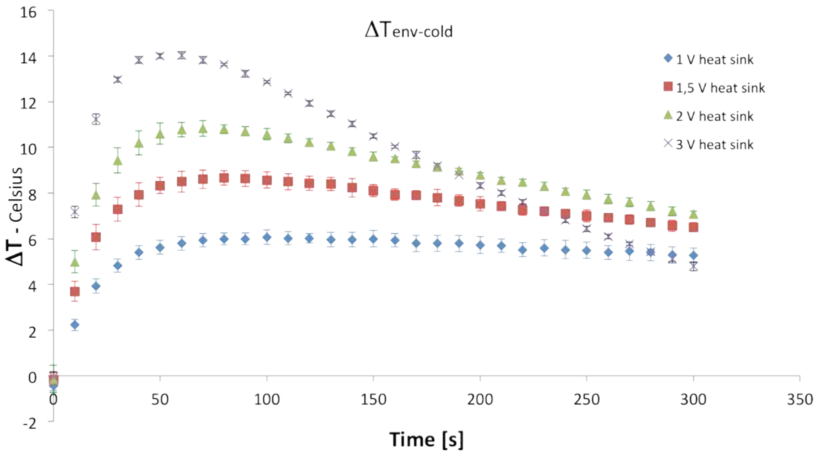

Figure 12. Difference of temperatures between the environment and cold side in relation to the time, for the peltier plates in cascade.

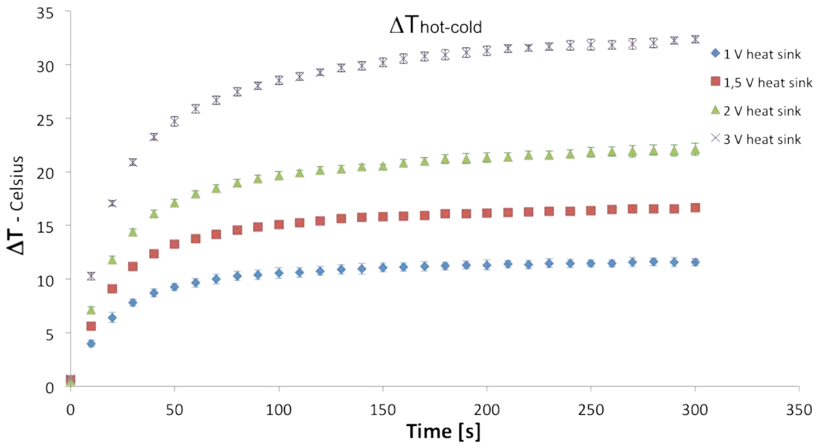

Figure 13. Difference of temperature between hot and cold side in relation to the time, for the peltier plates in cascade.

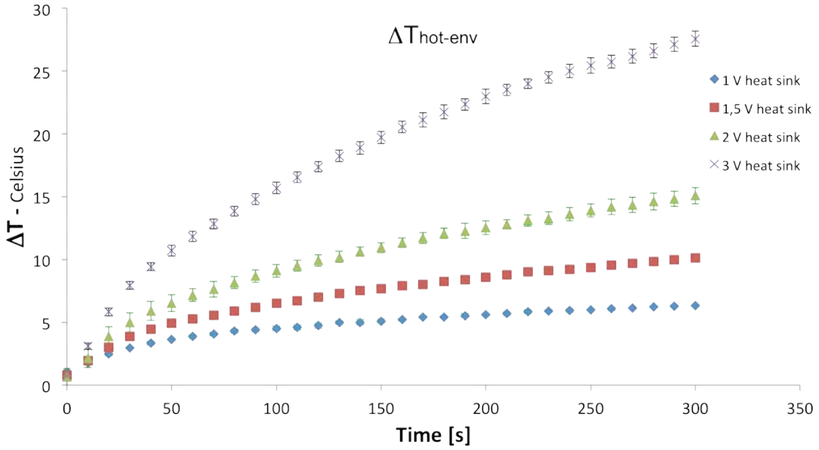

Figure 14. Difference of temperatures between the environment and hot side in relation to the time, for the peltier plates in cascade.

4. DISCUSSION AND CONCLUSION

The results of the tests confirmed the importance of the use of heat sink past. This result is expected because heat sink paste decreases the resistance of contact between two materials, since it eliminates the micro bubbles of air due to the roughness of the surfaces (Incropera *et al.*, 2008). Thus, the heat sink paste increases the flow of heat. However, these differences were not so significant for the finned surface dissipator, in the cases of the difference between the environment and cold side (Fig. 9). On the other hand, for the other cases of finned surface dissipator (Figs. 10 and 11), the difference is significant, albeit this difference was not so high.

Furthermore, for the finned surface dissipator and in the test of difference of temperatures between the environment and cold side (Fig. 9), the intensity of voltage has an influence only in the first seconds of activation. Afterwards, the performance of 1.5 V and 2 V are quite similar. This behavior can be also observed for the aluminum flat dissipator (Fig. 6).

For the case of peltier cascade, in all the differences of temperatures, the effect of voltage can be easily perceived (Figs. 12 to 14). However, for the most important test (difference of temperatures between the cold side and environment), the highest voltage at 3 V has presented a lower difference in comparison to other voltages (1 V, 1.5 V and 2 V), as can be observed in Fig. 12. This behavior can be explained due to the inversion of the flow of electron because of the high voltage applied, which can increase the temperature of cold side due to the overheat in the hot side.

For all the configurations, the results of the difference of temperatures between the hot and cold sides have presented a strong stability in comparison with the difference of both cold and hot sides with the environmental temperature. This stability is expected because of the mechanism of heat flow of the thermoelectric cold plates, that is, for a constant voltage, a heat flow should be constant and hence, the difference of temperature between the hot and cold side should be kept constant.

The most important result for the application of cool cap is the difference of temperature between the cold side and environment. Thus, the worst result was of aluminum flat plate as dissipator (Fig. 6) and the best result was of peltier in cascade mode (Fig. 12). The highest difference was around 8 ºC with 2 V and 1.5 V, which means a temperature of around 16 ºC for the cold side. This temperature is not enough for a clinical application, when it is compared to the fluid temperature of conventional cool cap (as mentioned before, it should be in the range of 8 to 12 ºC). Thus, an improvement of the heat dissipation is required for a successful application of this device with peltier plates.

An alternative to improve the heat dissipation is the use of a system with forced convection. However, the main problem of this system is related to the mechanical vibration derived from the fans and also, the increase of weight. These factors were considered and this is the reason for did not use a forced convection system as a heat dissipator. However, due to results with free convection system, preliminary studies of the forced convection devices for this cool cap have been done and they are a part of the future works.

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