DESIGN OF CARBON FOAM HEAT EXCHANGER FOR THERMOELECTRIC COOLER SYSTEM

Mohammad Almajail[1], Khalid Lafdi[1], and Antoine Delort[2]

[1]University of Dayton Research Institute, Dayton, OH 45469
[2]Arts ET Métiers Paris Tech, Rue Saint Dominique-BP 508, 51006 Châlons-en-Champagne, France.

Introduction

Workers in extreme hot environments often face very high temperatures, resulting in significant stress on the body's cooling mechanisms. Several types of cooling systems have been designed to regulate the individual body temperature [1-6]. These systems are inadequate solutions to light weight, lower power, and safe dismounted individual cooling for the optimization of human performance in hot environments. The solution to this problem is to develop a cooling system that does not require any bulky equipment and lasts longer than present passive cooling systems. Thermoelectric cooler (TEC) system can be utilized as a cooling system to provide cooled air to the garment and control the temperature of the system. The heat sink and heat exchanger of the TEC systems will be made of carbon foam. Due to the high thermal conductivity of carbon foam, the heat dissipation capabilities of TEC system can be improved. In addition, the density of carbon is relatively low and this will result in a lighter system to meet the user's requirements.

Experimental

Thermoelectric cooler system consists of a TEC module, hot side heat sink, and cold side heat exchanger. Figure 1 shows a schematic diagram for the TEC system. The cold air of the system is directed into the cooling vest through the heat exchanger using a blower and the hot air is dissipated to the external environment using a fan (Fig. 2).

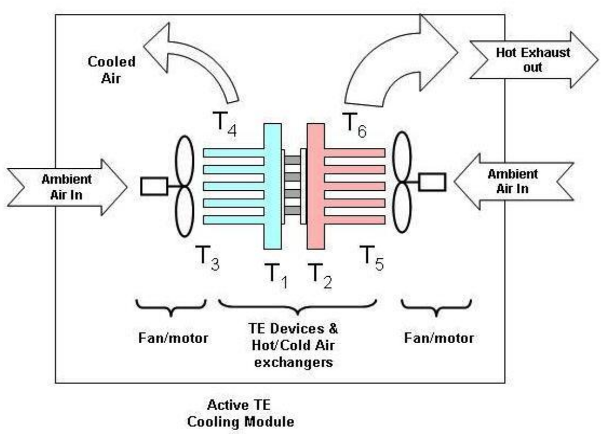

Fig. 1 Schematic diagram for thermoelectric cooler system

Initially, aluminum fins were used as a heat sink and heat exchanger with TEC. This system was modeled and its performance capabilities were determined by organizing an experimental set up to monitor the different parameters that affect the efficiency of the designed system. These parameters are: the temperatures of the hot and cold sides of TEC (T1 and T2), inlet and outlet air of heat exchanger (T3 and T4), and inlet and outlet air of heat sink (T5 and T6), and the flow rate of the outlet from heat exchanger was measured.

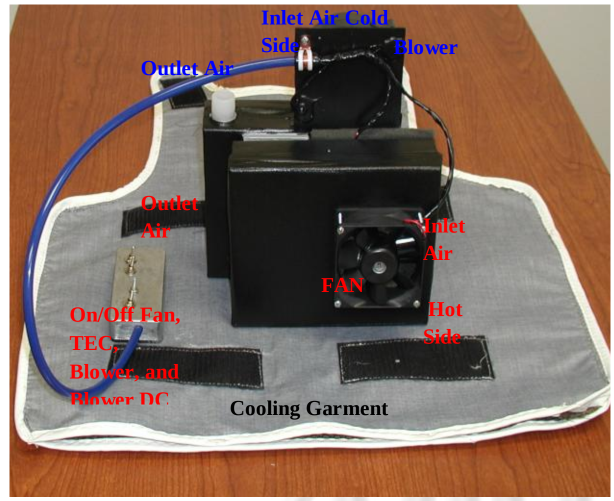

Fig. 2 Details for cooling vest system

The same measurements were performed on a new prototype that would use carbon foams instead of aluminum fins as a heat exchanger and a heat sink. Two kinds of carbon foams were used. One of them had low thermal properties and the other had high thermal properties. To determine the influence of the foam on the flow rate and on the performance of the heat exchanger, micro-channel configuration was used to be compared to aluminum fins (Fig. 3). In order to improve the mechanical and thermal properties of the carbon foams, the foams were electroplated with copper for a certain time to achieve a desired copper thickness. The setup was identical as the one used above. The tests were carried out for each kind of foam and geometry (for each test, the foams have the same thermal conductivity and configuration for the heat sink and heat exchanger). The acquisition principle was identical as well.

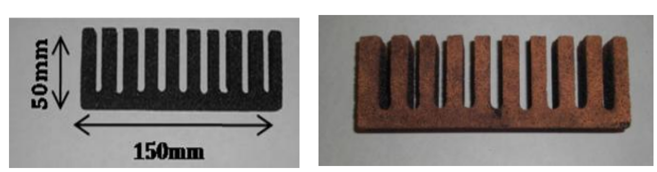

Fig. 3 Micro-channels configuration for machined foam

Results and Discussion

The comparison between the different material and configuration used in TEC is exhibited by considering each parameter separately. Table 1 shows the results for the measured effective thermal conductivities and the weight for the different used samples. It is clear that the coating process enhanced the foam with low thermal conductivity more than the foam with high thermal conductivity. Compared to aluminum fins, carbon foam with any type has less weight. The foam that weighs more than others is the coated one that has high thermal conductivity.

Table 1. Properties of Used Samples

Property	Aluminum fins	Low K		High K	
		Uncoated	Coated	Uncoated	Coated
Keff (W/m.k)	32.2	0.207	7.99	84.2	92.5
Weight (g)	242	93	115	131	174

Table 2 shows the air flow for all considered configurations that include aluminum fins. Apparently, air flow is proportional to the power; as the power increased the air flow increased and this is valid to all configurations. The type of the used material has no effect on the air flow which is only affected by the configuration. The air flow through aluminum fins is a little bit higher than carbon foam. This is due to the higher pressure drop through the carbon foam channels than aluminum fins.

Table 2. Air Flow CFM (ft³/min) for All Samples

v	Configurations				
	Alum. Fin	Low thermal conductivity		High thermal conductivity	
		Uncoated Foam	Coated Foam	Uncoated Foam	Coated Foam
15	1.083	0.846	0.716	0.812	0.813
18	1.250	1.028	0.844	0.942	0.942
21	1.362	1.099	0.942	1.032	1.032

The heat exchanger inlet temperature was the same in the all tests (41 °C - 42 °C). As the temperature at TEC cold side is low, the outlet temperature of heat exchanger is expected to be low. This, in addition to the thermal properties of the heat exchanger, will make higher temperature difference (ΔTcold) between the inlet and outlet air. For instance, the temperature at the cold side of TEC for aluminum fins is lower than others, thus, the outlet temperature is lower and ΔTcold is higher (Fig. 4). While the foam, with low thermal properties, has higher outlet temperature and lower ΔTcold.

The ambient temperature was considered as the inlet temperature for the heat sink for the all tests. Figure 5 shows the temperature difference (ΔThot) for all configurations at input power of 15 Volts. The results revealed that the best materials used as a heat sink is carbon foam with high thermal properties. This material exhibited also better performance than others. Aluminum fins didn't work very well as heat sink as in heat exchanger.

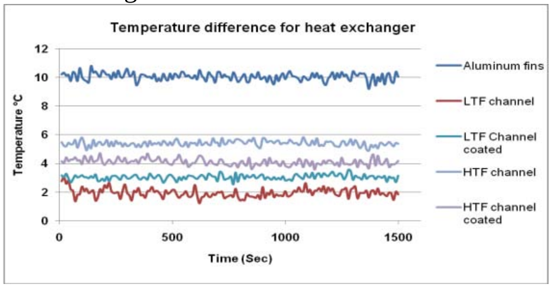

Fig. 4 ΔT of heat exchanger at 15 V for all configurations

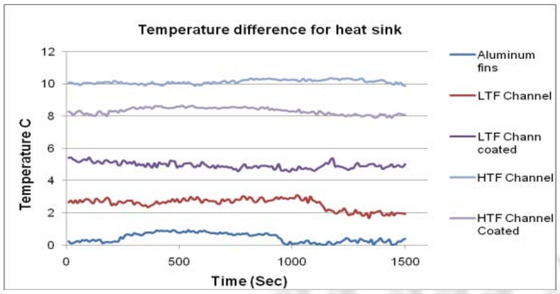

Fig. 5 ΔT of heat sink at 15 V for all configurations

Conclusions

Carbon foams and aluminum fins were used to cool the ambient air through a heat exchanger and dissipate heat build up from the heat sink. Aluminum fins provided a sufficient temperature drop through the heat exchanger but didn't dissipate the heat from the heat sink. Carbon foam with high thermal conductivity provided a great heating ability under higher voltage inputs. The carbon foam with low thermal conductivity did not provide any significant cooling or heating effect. Besides its thermal conductivity, the main advantage of the carbon foam was its weight. For they are brittle materials, the coating with copper is an advantageous way to strengthen the foam without increasing considerably its weight. For a portable use, carbon foam appeared to be very effective.

References

[1] Muke G. Preliminary testing of cold suits for mining industry, Gluckauf and Translation, 1982; 118: 394-399.
[2] Margret T, Dorothy F, David E. Influence of garment design on elite athlete cooling, Sport Technology, 2008; 1; 117-124.
[3] Raven PB, Dodson A, Davis TO. Stresses involved in wearing PVC supplied–air suits: a review, American Industrial Hygiene Association, 1979, 40: 592-599.
[4] Nicholl A, Martin R, Graveling RA. Active man-cooling: Edinburg Institute, IOM Report TM/83/16 (1983).
[5] Webbon B, Williams B, Kirk P, Elkins W, Stein R. A portable personal cooling system for mine rescue operations, Journal of Engineering for Industry, 1978; 100: 53-59.
[6] Troy C, Bruce C, Daniel G, Samuel C, Michael C. Efficacy of body ventilation system for reducing strain in warm and hot climates, European Journal of Applied Physiology, 2008; 103: 307-314.