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Portable Thermoelectric Cooler Box Performance with Variation of Input Power and Cooling Load

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Abstract – The thermoelectric module is a device that works by using the Peltier effect when electrical power supplied on it. In this study, the thermoelectric module is applied as thermoelectric cooler (TEC) using air cooling heat sink where cooling box capacity is 22 L. This paper experimentally investigates the thermal performance of thermoelectric cooler with a variation on input power and cooling load. The investigation was conducted by three variations on input power (50.5W, 72.72W and 113.64W) and by two variations of the cooling load using mineral water (1440 mL and 2880 mL) with input power 113.64W. The box temperature achieved at input power 50.5W, 72.72W and 113.64W are 19.98°C, 19.77°C and 18.52°C, respectively. While at the cooling load of 1440 mL and 2880 mL, the temperature achieved in the box are 22.45°C and 23.32°C, respectively. The test results showed that in variation on the input power from low to high, the temperature in box becomes lower on high input power and it causes the lower of Coefficient of Performance. This is because more energy could be absorbed on high input power. In the cooling load variation, the greater the cooling load given in cooling box, then the longer the box temperature stability can be achieved because of more energy needed for decreasing the temperature of cooling box.

Key words: Thermoelectric, Peltier, cooling, heat sink, cooler, temperature

Introduction

The thermoelectric systems are solid-state heat devices that require a heat exchanger to dissipate heat directly into electricity or transform electric power into thermal power and it works as a heater or a cooler. This device is based on thermoelectric effects involving interactions between the flow of heat and electricity through solid bodies. These phenomena, called Seebek effect and Peltier effect. The thermoelectric phenomena (Seebeck effect) was first observed by Thomas Johann Seebeck, in 1821. Thermoelectric cooling system is based on an effect was discovered by Jean Charles Peltier Athanasius in 1834. Just by applying a low DC voltage to this module, one surface gets cold and the other surface gets hot. And just by reversing the applied DC voltage, the heat moves to the other direction, this thermoelectric device could be either heating or cooling, this Peltier effect can be harnessed to transfer energy as heat (Camargo and Oliveira, 2011; Alaoui, 2011; Sharma *et al.*, 2014; Zebarjadi, 2015; LinGen, 2016).

The thermoelectric module as shown in Figure. 1 (Mahan, 2016) consists of two thin rigidity ceramic wafers with a series of P and N doped bismuth-telluride semiconductor material sandwiched between them. The thermoelectric semiconductor is connected by copper conducting strips in serials. When the electrons move from the P type material to the N type material through an electrical connector, the electrons will jump to a higher energy state with absorbing thermal energy (cold side). Continuing through the lattice of material; the electrons flow from the N type material to the P type material through an electrical connector dropping to a lower energy state and releasing energy as heat to the hot side of heat sink (Alaoui, 2011; Sharma, 2014; Zhao and Tan, 2014; He, 2015).

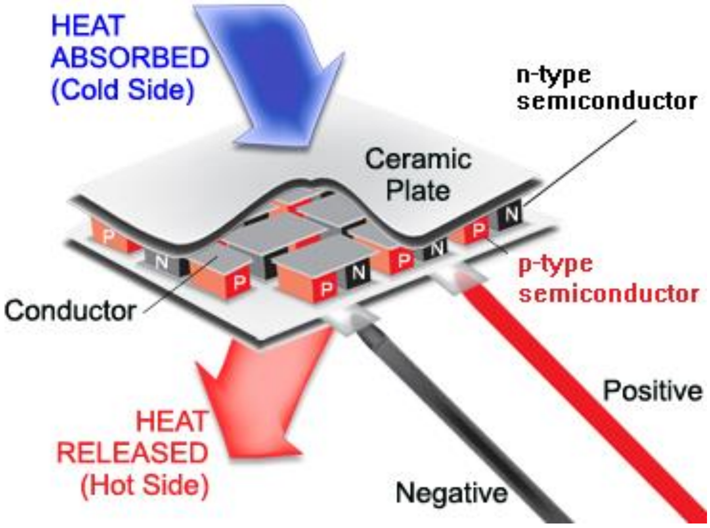

Figure 1. Thermoelectric module (Mahan, 2016)

There are good review papers on thermoelectric cooling and potential applications, including material, modeling and thermoelectric cooler (Zebarjadi, 2015, Shaikh and Chopra, 2014, Yang *et al.*, 2005). Yang *et al*, 2005, Filippsechi *et al.*, 2006, Hou *et al.*, 2009 and Barry *et al.* 2015 reported thermoelectric cooling (TEC) applications for micro devices, mini refrigerator, applications of heat sinks and hotspot cooling and thermoelectric performance integrated with heat exchangers.

More recent applications use TEC with different prototype design for refrigeration system (Martin-Gomez *et al.*, 2016, Martinez, 2016). Vadi and Kulkarni, 2015 presented analysis of thermoelectric cooler performance using two modules connected in parallel, with Peltier module of 231W, 15.4V, 15A, TEC1-12715. The result obtained the temperature difference of 10^0C, inside a cooler box of volume 66500cm^3 for 25 minutes, where power input is 195.6W. The large temperature difference of TEC module affected the performance refrigeration system, where analysis carried out on the refrigerator wiht different TEC module location for performance enhancement (Bajaj *et al.*, 2016).

Most of previous studies are focused on TEC with different models and prototypes of Peltier effect refrigeration system. This work focuses on the performance investigation of thermoelectric cooler under various input power and cooling load where the influence of inlet electric current and temperature on application of thermoelectric modules are also investigated.

Materials and Methods

The portable thermoelectric cooling box with 22 L capacity as shown in Figure 2 was fabricated by using nine TEC modules. The portable thermoelectric cooler box (PTECB) dimensions are given in length x width x height (36.5 cm x 25.5 cm x 26.5 cm). The main component of PTECB besides TEC are heat sink (2 pieces), fan (5 pieces), thermoelectric controller, battery (12 V, 7,2 A) and UPS 600VA.

Figure 3 shows the test points of data measurement. The test data records were performed by measuring the electrical voltage and current and the temperature at cold side and hot side of heat sink (T_c and T_h), box, and ambient every 10 minutes for 2 hours. Based on the TEC1-12706 specifications, the total of electrical resistant is 1,98Ω, where seebeck coefficient is 0.050774 (V/K) and thermal conductivity of TEC is 0.1391 (W/mK) (Haidar *et al.*, 2011).

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Figure 2 Thermoelectric Cooler Box

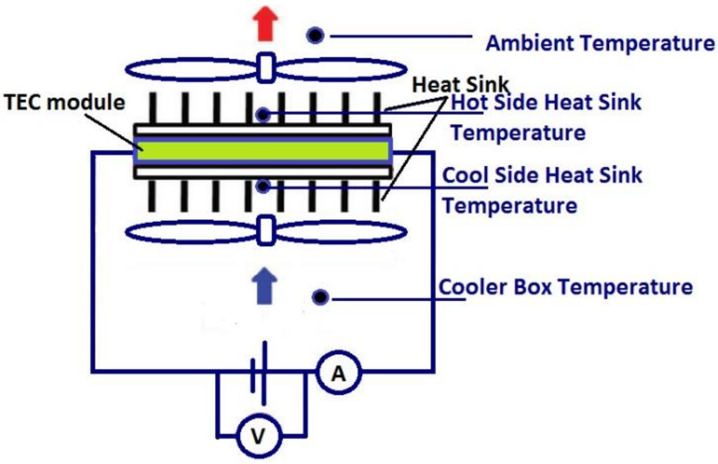

Figure 3 Measurement test points

This study was conducted in experimental design to investigate the performance of PTECB/. An integrated thermoelectric module (TEC1-12706) with cascade system was used on PTECB. Each cascade consists of three modules, two modules in the bottom and one module in the top as shown in Figure 4. Three cascades were used and every cascade was arranged in parallel as shown in Figure 5.

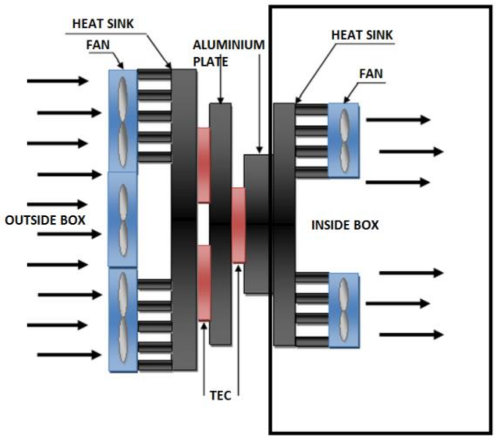

Figure 4 Schematic of cascade system

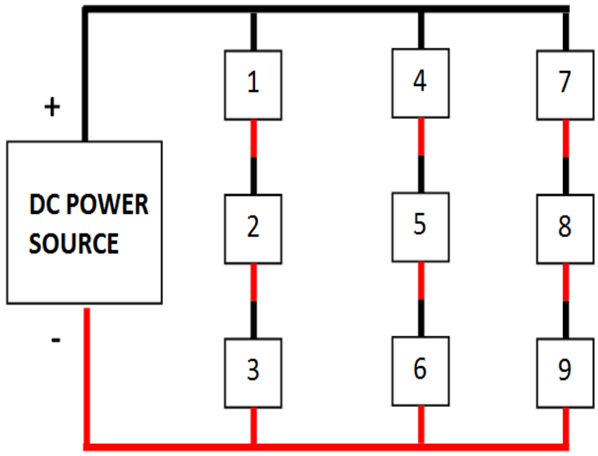

Figure 5 Three cascade system in parallel

Design of material

To calculate the absorbed heat in cold side (Q_c), the wasted heat in hot side (Q_h) and the performance (*COP*) of the box cooler are presented in Eq. (1) - Eq. (4) (Jugsujinda *et al.*, 2011).

$$Q_c = \alpha I T_c - \frac{1}{2} I^2 R - K_t (T_h - T_c) \tag{1}$$

$$Q_h = \alpha I T_h + \frac{1}{2} I^2 R - K_t (T_h - T_c) \tag{2}$$

$$P_{in} = Q_h - Q_c \tag{3}$$

$$COP = \frac{Q_c}{P_{in}} = \frac{Q_c}{Q_h - Q_c} = \frac{T_c}{T_h - T_c} \tag{4}$$

Table 1 shows several materials that can be used to manufacture cooling box of PBC. The mentioned parameters are thermal conductivity (k), density (ϱ) and the unit price. Judging from the ability of thermal conductivity, copper is the best materials for the inner wall, but they are expensive and heavy (it has the greatest value of ϱ). Aluminum is the second best material for inner wall with low price and lightweight (smallest value of ϱ). Therefore, it will appropriate to select aluminum as the material for the inner wall of a portable beverage cooler. In Eq. (1) – Eq. (4): P_{in} is the power input (W), a is the Seebeck coefficient (Volt/K), I is the electric current (A), R is the electrical resistant of the TEC material (Ω), K_t is the thermal conductivity of the thermoelectric element (W/mK) and *COP* is the coefficient of performance of the cooler system.

Results and Discussion

This research was conducted by varying the input power through the variation of electrical voltage. Table 1 shows the input power on electrical voltage variation Figure 6 and Figure 7 show the cool side of heat sink temperature and cooler box temperature int the variation of input power (50.5 W, 72.72 W and 113.64 W) for 2 hours operation respectively. The value of input power in the equipment affects the temperature of cooling module. The result shows that the temperature at cool side of heat sink and cooler box decreases with the increasing of the input power that supplied to the system, because of the more heat absorption in cool side of TEC modules so that the lower the temperature obtained at cool side of heat sink and cooler box.

Table 1 Input power on electrical voltage variation

R (Ω)	V (Volt)	I (Ampere)	P (Watt)
1,98	10	5,05	50,5
1,98	12	6,06	72,72
1,98	15	7,57	113,64

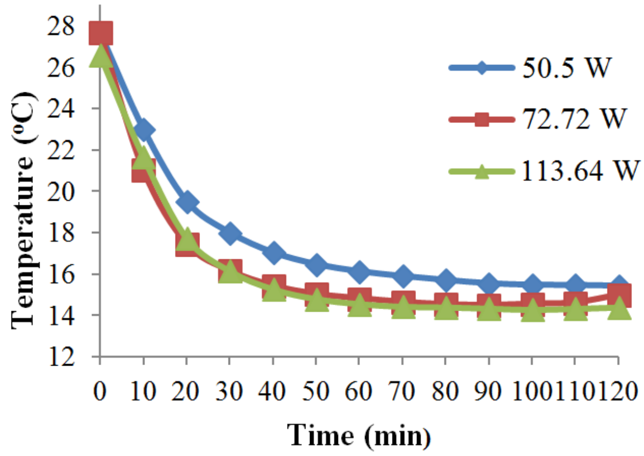

Figure 6 Temperature of cool side of heat sink

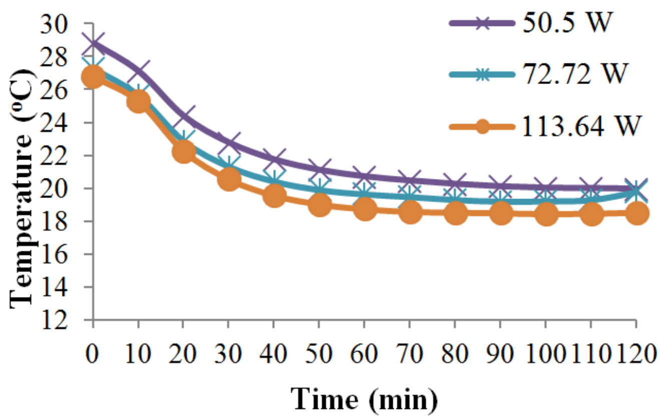

Figure 7 Temperature of inside cooler box (°C)

The heat should be rejected from beverage cans and then is absorbed by thermoelectric cooler are vary depend on cooling time. The faster cooling time is needed to achieve cooling temperature the more heat load should be rejected in such period of time. The Figure 6 shows that in 20 minutes in design 3 the energy as heat that should be absorbed by thermoelectric is 25.932 W, while the lowest is design 2 with only 11.199 W.

Figure 8 and Figure 9 show the hot side of heat sink temperature with ambient temperature and COP of cooler box in the variation of input power (50.5 W, 72.72 W and 113.64 W) for 2 hours' operation respectively. The amount of input power also affects the temperature that achieved in the hot side of heat sink. The result shows the hot side temperature of heat sink increases with increasing of the input power, because of the more heat absorption in cool side of TEC (inside cooler box), the more heat rejection in hot side of TEC (outside cooler box) so that the temperature of the hot sink will rise.

The ambient temperature during the test tends to be similar, so it does not affect the temperature achieved in the hot side of heat sink with a different power input. The equations 1, 2 and 4 were applied to calculate the COP value for each input power, the results show that the COP value decreases from 0.852, 0.641 and 0.414 with the increasing of input power value from 50.5W, 72.72W and 113.64W. This is because when input power increases, it means the heat absorption increasing too, so this condition will cause temperature at cool side of heat sink decreases as shown in Figure 8.

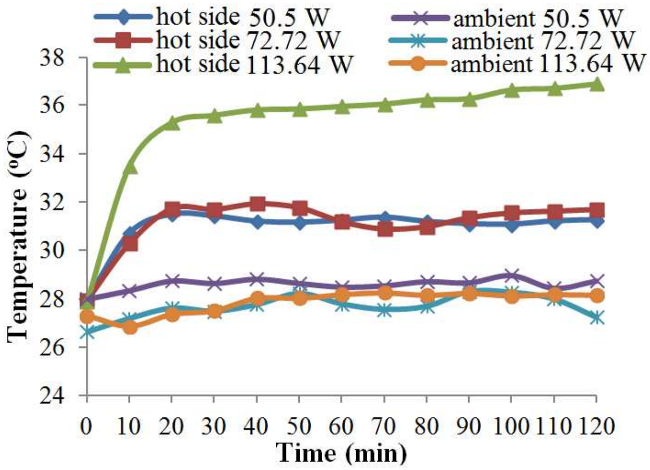

Figure 8 Hot side temperature of heat sink and ambient temperature in variation of input power

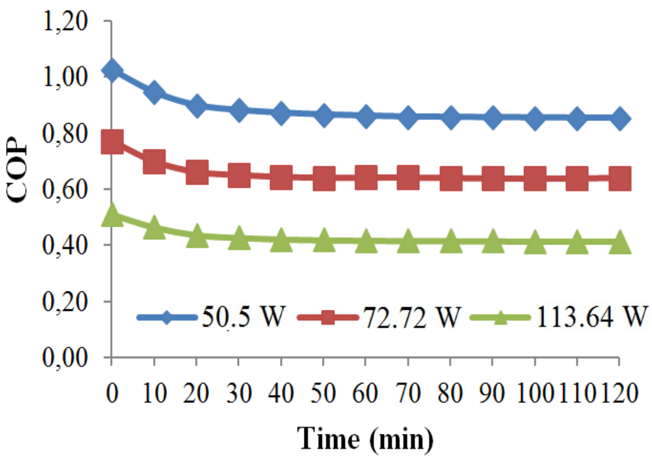

Figure 9 COP of the cooler box in variation of input power

Figure 10 shows the temperature condition of cooler box (cool side of heat sink, hot side of heat sink, inside cooler box and ambient temperature) at input power 113.64 W with cooling load of water 1440 mL. The average temperature of box cooler for 2 hours operation are 19.37°C at cool side of heat sink, 44.71°C at hot side of heat sink and 22.45°C at inside box, where the average temperature of ambient is 29.31°C.

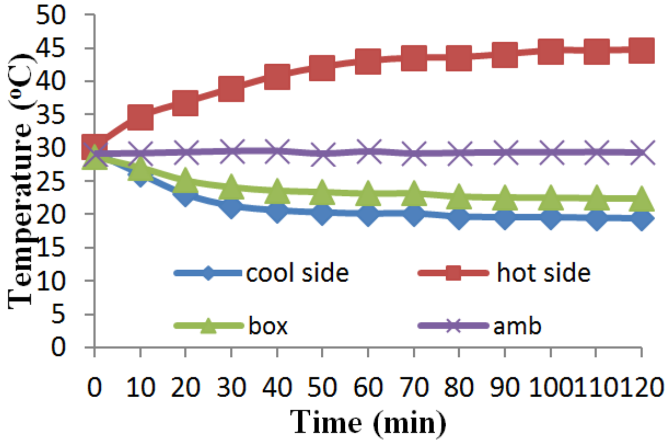

Figure 10 Temperature of Cooler box with cooling load 1440 mL

Figure 11 shows the temperature condition of cooler box (cool side of heat sink, hot side of heat sink, inside cooler box and ambient temperature) at input power 113.64 W with cooling load of water 2880 mL. The average temperature of box cooler for 2 hours operation are 20.59°C at cool side of heat sink, 44.40°C at hot side of heat sink and 23.32°C at inside box, where the average temperature of ambient is 31.2°C. Through comparison of the test results with the cooling load variation as shown in Figure 6a and 6b, with 113.64 W input power for different cooling load, it can be stated that there was no significant effect on the temperature of the cooler box. This is due to the differences in ambient temperature by 2°C provide temperature difference 1°C at cooler box, so that if the test is done at the same ambient temperature, the temperature cooler box tends to be similar, because the ambient temperature tend to affect the temperature of the box as reported by Dutta and Aritome (2000).

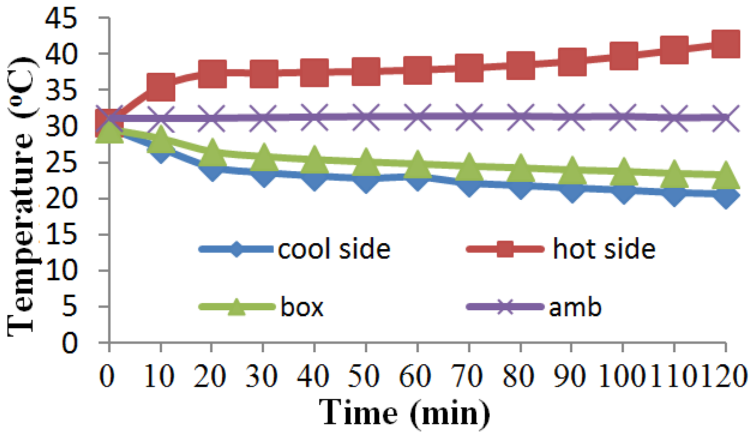

Figure 11 Temperature of cooler box with cooling load 2880 mL

Conclusions

The investigation of thermoelectric cooler with variation input power and cooling load have been presented. It can be concluded that temperature at cool side of heat sink and cooler box decreases with the increasing of the input power that supplied to the system, because the more heat absorption in cool side of TEC modules so that the lower the temperature obtained at cool side of heat sink and cooler box. The hot side temperature of heat sink increase with increasing of the input power, because of the more heat absorption in cool side of TEC (inside cooler box), the more heat rejection in hot side of TEC (outside cooler box which cause the temperature of the hot sink will rise. In variation on the input power from low to high, the temperature in box becomes lower on high input power and causes the lower of COP. This is because more energy could be absorbed on high input power. In the cooling load variation, the greater the cooling load given in cooling box, then the longer the box temperature stability can be achieved because of more energy needed to decrease the temperature of cooling box.

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