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ACTIVE PASSIVE THERMOELECTRIC SYSTEM HELMET FOR PERSONAL COMFORT

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Abstract. This study aims to make motorbike helmet using thermoelectric technology by utilizing a Peltier effect. The main system component consists of a double layer heatsink, fan, copper plate, and thermoelectric module. 12 DC Voltage applied to module, and temperature differences rise created. Heat in hot side rejected to environment by heatsink and fan. A copper mounted to cold side to sprayed out the cool sensation to a whole helmet. This study was conducted prototype to analyse the performance of cooling. The results showed a fair enough result that indicated prototype of a cooling system based on thermoelectricity for a motorcyclist helmet can reduce the inside helmet temperature by 18%. The results showed a fair enough result that indicated the temperature inside helmet was reduced from 33°C to 27°C in approximately 10 minutes. The highest temperature on hot side is 50°C and the lowest temperate on cold side is 20°C. Q total in helmet to absorb 53 watts; the thermoelectric cold side heat absorption 42.5 watts, the thermoelectric hot side heat emissive 93.5 watts; the heatsink heat rejected 70 watts; the fan specification is 12V DC 0.9A and it can rejected heat by 30 watts.

1. Introduction

In Indonesia, thermoelectric research is more developed in the field of thermoelectric applications as refrigerator and heater. As research conducted by Gontor (2015) about application of thermoelectric generators as power plant with cold side using water temperature 10 º C and research conducted by Sri (2017) about Peltier effect application as a heated box and cooling Arduino UNO-based microprocessors [10]-[11].

In automotive, research on thermoelectric has the same trend as the two studies above. Research is only focused on the utilization of thermoelectric as a vehicle electrical generator. As an example of the research of Latif (2015), which research about potential of electrical energy in the exhaust of motorcycles. The results are applied as an electrical generator of vehicles [2], [7]. There is no domestic research that utilizes thermoelectric as a means of supporting comfort, especially as a cooler on helmet. Thermoelectric constructed by two different semiconductor pieces, one N type and the other P type. Material of P type is a material that lacks electrons and material of N type excess electrons. When the material is given a temperature difference, the electrons will move from the heat temperature side to the cooler side of the temperature. Conversion of energy due to temperature differences into electrical energy called Seebeck effect [4],[8].

2. Methodology

Peltier in his research found an opposite behaviour of Seebeck experiment result. Seebeck found that if we give a temperature differences on a semiconductor material it will generate the electron movement from one semiconductor to others. The movement generates electricity by 1.5V DC. By reversing the Seebeck experiment, Peltier found that if he gives an electric to the two semiconductor materials it will generate both, a decrease of temperature and increase of temperature on

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semiconductor material. Heat (Q) absorbed at one side because and Heat also rejected at the other side. A connection of metal junction will generate the discharged degree at the opposite. If we give the electricity within the circuit, it was change to get a distinct configuration. If a DC voltage (E_{in}) is applied to the circuit as a result, a little cooling effect occurs at thermocouple junction.

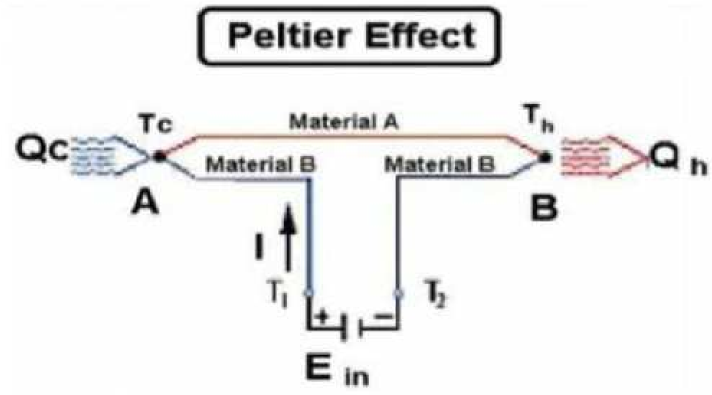

Figure 1. Peltier Effect

We can calculate the Seebeck effect using this formula:

$$S_{21} = S_2 - S_1 = \frac{V_2 - V_1}{T_2 - T_1} \qquad eq. 1$$

Where, V is voltage (V), S_{21} is Seebeck coefficient of material A and B (VC^{-1}), T_2 is thermoelectric hot side temperature (°C) and T_1 is thermoelectric cold side temperature (°C) [1], [4].
The apparatus setting use in this study is show in the Figure 2.

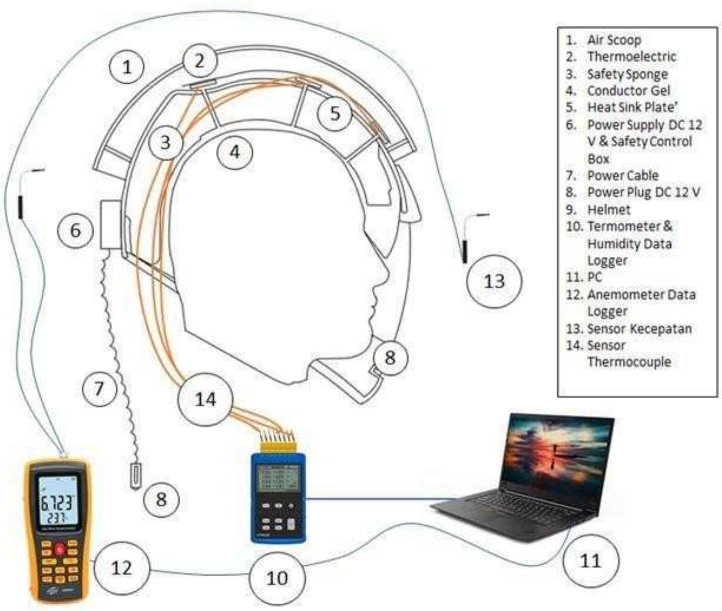

Figure 2. The apparatus setting of active passive thermoelectric system helmet

The Stefan-Boltzmann law formulated the black body power radiation of temperature. The state is the total energy radiated per unit surface area of a black body across of all wavelengths per unit time is

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directly proportional to the fourth power of the black body's thermodynamic temperature. For radiation heat of transfer between two materials, the equation is:

$$Q = \varepsilon. A. \sigma[T_{absorb} - T_{reverence}] \qquad eq. 2$$

As T_{absorb} and $T_{reverence}$ is a human head inside helmet temperature and human comfort temperature than the equation became:

$$Q = \varepsilon. A. \sigma[T_{head} - T_{comfort}] \qquad eq. 3$$

Where, ε is the emissivity of head equals to = 0.98, A is the surface area of the head, assumed it radius be R = 0.1m, thus $A = 4\pi r^2 = 0.125664\ m^2$, σ is Stefan–Boltzmann constant = 5.67×10^{-8}, T_{head} is temperature of head = 37°C = 310 K and $T_{comfort}$ is comfort temperature = 25°C = 298 K [4]-[5].

One of the heats that we must observe is the metabolic equivalent is a measure expressing the energy cost for physical activities. It is equal to the rate of energy produced per unit surface area of an average person seated at rest.. It can be set by convention approximately to Metabolic equivalent known as MET and its value is equal to = 1 kcal/kg*h = 4.19 kJ/kg*h = 1.16 W/kg. Also MET known by 1 MET = 58 W/m^2,

For thermoelectric module, there are two different energy occurs, an absorbent heat and emissive heat. They formulated by:

Q absorb at cold side (Q_{abs}):

$$Q_{abs} = \alpha . I . T_c - \frac{\Delta T}{\Phi} - \frac{I^2 . R}{2} \qquad eq. 4$$

Q emissive at hot side (Q_{em}):

$$Q_{em} = \alpha . I . T_c - \frac{\Delta T}{\Phi} + \frac{I^2 . R}{2} \qquad eq. 5$$

Where:

Thermoelectric Seebeck Coefficient (α) = 0.065 V/K
Thermoelectric Electricity Resistance (R)
Thermoelectric Thermal Resistance (Φ) = 1.1 K/Watts
Thermoelectric Hot Side Temperature (T_{hot})
Thermoelectric Cold Side Temperature (T_{cold})
Thermoelectric Temperature Difference (ΔT)

Heatsink heat transfer calculated by:

$$Q = N. (K. A. n. \Delta T.)\ Tanh\ (n. L) \qquad eq. 6$$

Where, T_1 is temperature at fin base, T_2 is room temperature, w is fin width, t is fin thickness, K is fin material thermal conductivity = 205 W/mC, h is convective heat transfer coefficient = 5.7 W/m^2C, L is fin length, N is number of fins[1],[3],[4],[5].

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3. Result and Discussion

The main concept of the helmet cooling is removing the heat generated inside a helmet by using a thermoelectric module. The main disadvantage of the thermoelectric module is if we cannot remove the heat in a hot side, the heat will affect the cold side also. Increasing heat on a hot side must be rejecting to the environment or it will be increasing the temperature in a cold side.

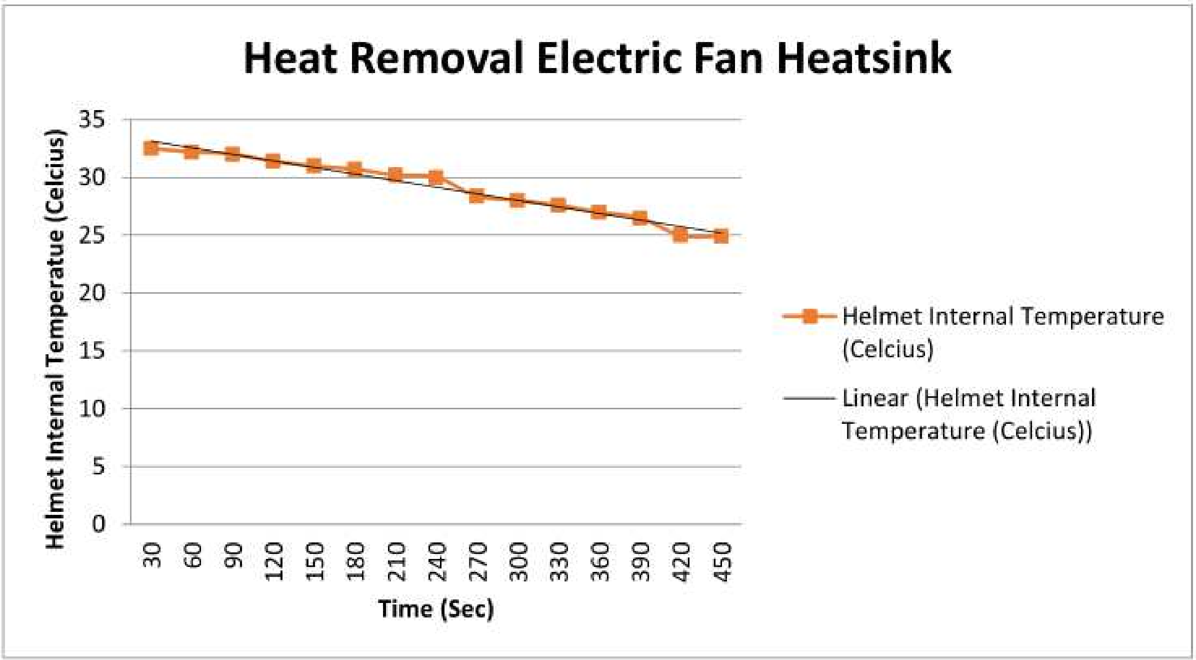

Figure 3. Heat removal electric fan heatsink

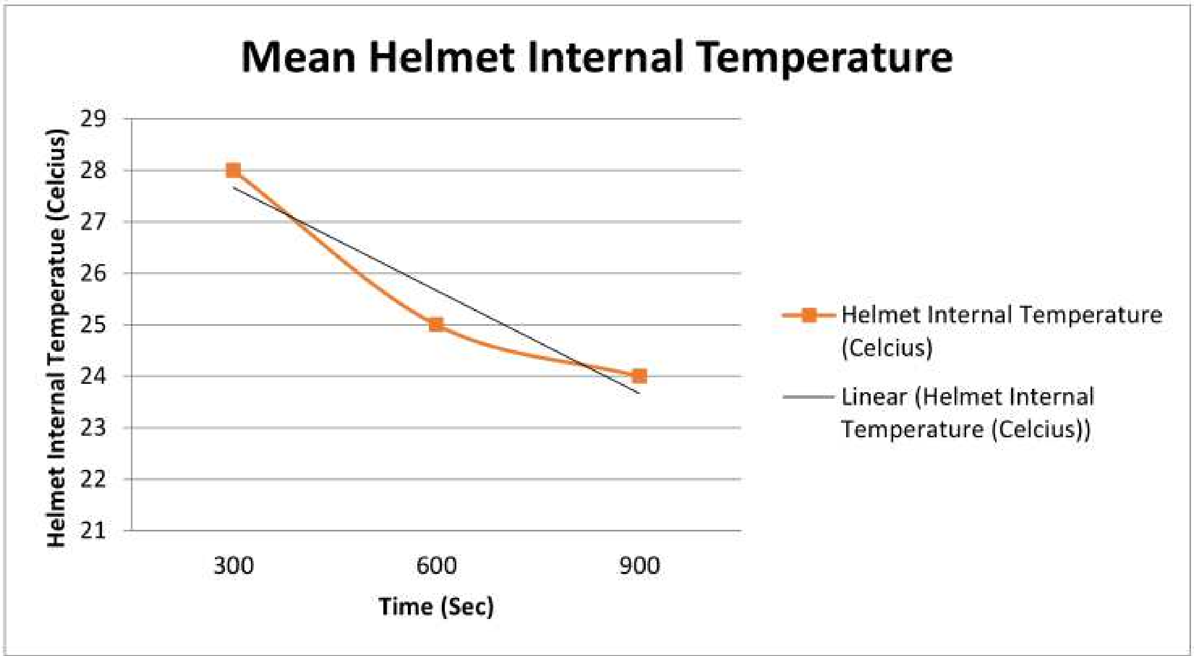

Figure 4. Mean helmet internal temp.

In this study we try to rejecting the heat on a hot side by using a heatsink coupled by electric fan, this method also known as active passive convection heat transfer. Before we select the heatsink electric

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fan, we must first calculate the heat that we must remove. Heat to be removed is a heat inside the helmet. Heat inside the helmet must be calculating first before we design the heatsink component.
Rejected heat is known as a total heat (Q_{total}), it calculated by enumerate human head, convection heat, human metabolic heat.

1. Human head is calculating by using an eq.2:

$$Q1 = \varepsilon . A . \sigma . [T_{head} - T_{comfort}]$$

$$= 0.98 \text{ x } 0.12\text{m}^2 \text{ x } 5.67.10^{-8} \, [3104\, ^{o}\text{K} – 2984\, ^{o}\text{K}] = 7.42 \text{ Watts}$$

2. The convection heat transfer given:

$$Q2 = h_{air}\, A\,(T_{head} - T_{comfort})$$

$$Q2 = 50\, \frac{w}{m^2}\, ^{\circ}\text{C}\, x\, 0.12\, m^2\, ((273 + 30) - (273 + 27))$$

$$Q2 = 31.25 \text{ Watts}$$

3. Human Metabolic Heat
   Next, we must calculate the human metabolic equivalent, for a rider who riding a bike it assumed that it consumed 2 MET energy, It noted as Q3, Q3 can be calculated by: Q3 = 2 x 58.2 = 116.4 W/m^2.

$$Q3 = 116.4 \text{ x } 0.12 = 14 \text{ Watts}$$

   Total heat must rejected is equals to,

$$Q \text{ total} = Q1 + Q2 + Q3$$

$$\text{Total} = 7.42 + 31.25 + 14 = 52.67 \text{ watts} = 53 \text{ Watts}$$

This total heat (Q_{total}) become a heat we must remove from the helmet if we want get a comfort head condition. We can remove this heat by absorb it by face it with a cold side of a thermoelectric module. Heat in thermoelectric module can be divide by two heat, heat absorb at cold side and heat emissive at the hot side. Based on our study we know that:

1. Thermoelectric Seebeck Coefficient (α) = 0.065 V/K
2. Thermoelectric Electricity Resistance (Ω)= 1.65 ohm
3. Thermoelectric Thermal Resistance (Φ) = 1.1 K/Watts
4. Thermoelectric Hot Side Temperature (T_{ho}t) = 35 ^{o}C
5. Thermoelectric Cold Side Temperature (T_{cold}) = 5 ^{o}C
6. Thermoelectric Temperature Difference (ΔT) = 30 ^{o}C

Then we can calculate:

Q absorb at cold side (Q_{abs})

$$Q_{abs} = \alpha . I . T_c - \frac{\Delta T}{\Phi} - \frac{I^2 . R}{2}$$

$$Q_{abs} = 0.065 . 5 . (273 + 5) - \frac{30}{1.1} - \frac{5^2 . 1.65}{2} = 42.5\, Watts$$

Q emissive at hot side (Q_{em})

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$$Q_{em} = \alpha \,.\, I \,.\, T_c - \frac{\Delta T}{\Phi} + \frac{I^2 \,.\, R}{2}$$

$$Q_{abs} = 0.065 \,.\, 5 \,.\, (273 + 35) - \frac{30}{1.1} - \frac{5^2 \,.\, 1.65}{2} = 93.5\, Watts$$

Voltage need by thermoelectric module is calculated by:

$$V = \alpha \,.\, \Delta T \,.\, T + I \,.\, R$$
$$V = 0.065 \,.\, 30 + 5 \,.\, 1.65 = 10.2\, V$$

Thus, Q_{abs} = 42.5 watts, it can be the amount of heat can be absorbing by thermoelectric in cold side. This number must be comparing by the Q_{total} (the heat must be absorbing in helmet), comparing the number we can get fact that $Q_{abs} < Q_{total}$ (42.5 watts vs 53 watts). Differences 10 Watts is a heat that cannot be absorbing by the thermoelectric module. We assume that it not a really a big thing because 53 watts is a maximal number that we predict happening for most people, in real condition it can be less.

The next problem is we must remove the heat generated in a hot side. This heat can affect the cold side, which it can reduce the amount of heat absorbing in a cold side. The heat must be removed by using an electric fan heat sink. The heat rejected by heat sink is calculated by:
Assume that this fin case is a fin with a finite length and insulated at end.
Thus heat flow rate is:

$$Q = N.\,(K.\,A.\,n.\,\Delta T.\,)\; Tanh\,(n.\,L)$$

From this study we get:

1. Temperature at fin base, T_1 = 122 °F
2. Room Temperature, T_2 = 68 °F
3. Fin width, w = 4 in
4. Fin thickness, t = 0.4 in
5. Fin material thermal conductivity, K = 205 W/mC
6. Convective heat transfer coefficient, h = 5.7 W / m^2C
7. Fin length, L = 4 in
8. Number of fins, N = 50

The calculations are Fin width (w) = 0.102 m; Fin thickness (t) = 0.0102 m, so:
Fin base area, A =

$$A = w \,.\, t\ (m^2)$$
$$A = 0.001032\ m^2$$

Temperature difference,

$$\Delta T = T1 - T2$$
$$\Delta T = 54\ ^oF = 12.22\ ^oC$$

For thin fin,

$$n = (2 \,.\, h/K \,.\, t)^5\ n$$
$$= 2.34$$

L = 0.102 m n . L = 2.54 x 0.1 = 0.238

$$Tanh\ (n \,.\, L) = 0.23332$$

Heat flow rate,

$$Q_{heatsink} = N\ (K\ A\ n\ \Delta T)\ tanh\ (n \,.\, L)$$
$$Q_{heatsink} = 70.59\ Watts = 70\ Watts$$

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From calculation we know that the heatsink only can remove 70 watts of heat ($Q_{heatsink}$). It needs 30 Watts more to be rejected. As we guess earlier that the passive cooling cannot perform to remove all the heat, so we must have equipped the heatsink with an electric fan as an active cooling.
The electric fan air velocity known as a distance travelled per unit of time, usually expressed in Linear Cubic Feet per Minute (CFM). For fan supplied by 12V DC voltage with load of current 0.9A, We can get the number of is CFM= 104. This graph shows the correlation between CFM and Heat to be removed.

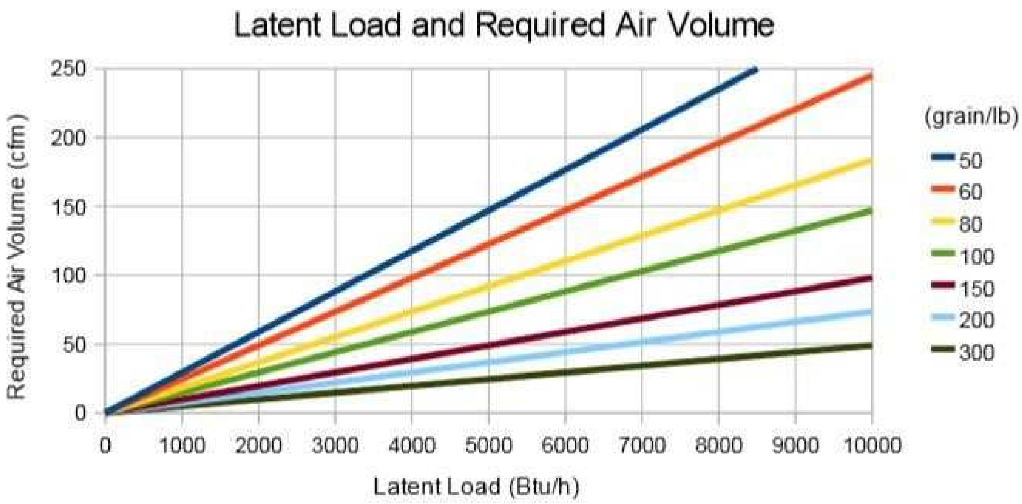

Figure 5. The correlation between required air volume (CFM) and heat to be removed

Converting the heat 30 Watts to Btu/h get 102 Btu/h. Based on the graph above we get the CFM needed to reject the heat is 50 CFM. So, from this calculation we know that the 12V DC 0.9A fan fairly enough to reject the heat.

4. Conclusion

The prototype of a simple active cooling system generated by thermoelectricity for a motorcyclist helmet can reduce the inside helmet temperature by 18%. The results showed a fair enough result that indicated the temperature inside helmet was reduced from 33°C to 27°C in approximately 10 minutes. The highest temperature on hot side is 50°C and the lowest temperate on cold side is 20°C. Q total in helmet to absorb is 53 watts; the thermoelectric cold side heat absorption is 42.5 watts, the thermoelectric hot side heat emissive is 93.5 watts; the heat sink heat rejected is 70 watts; the electric fan specification is 12V DC 0.9A and it can rejected heat by 30 watts.

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