Experimental study of thermoelectric refrigerator performances: effect of air flow direction on the ribbed plat-fin heat sink at cold side of TEC

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Abstract. This study aimed to investigate the effects of the direction and flow rate of air in the heat sink to the performance of the thermoelectric coolers (TEC). A ribbed heat sink is placed on the cold side of the TEC as a heat exchanger component in the Styrofoam cooler box, while a water block placed on the hot side of TEC, the temperature, and flow rate of coolant is maintained constant. Airflow on the heat sink in the cooling room has been varied by two different types of fan modes; blowing and sucking. Air velocity is also varied for both flow conditions. The investigation showed that the sucking mode of fan at the lowest speed of airflow would generate the lowest temperature of the cooler compared with the other combinations of fan modes and speed of airflows. Based on these results, showed that the fan mode and velocity of an airflow across the heat sink affect the thermoelectric performance.

1. Introduction

The air forced convection heat sink is mostly used in the application in the box thermoelectric coolers, and the behavior of fluid works also influence the performance of the cooler. This study intended to investigate the effect of the direction and rate of airflow to the heat sink of the Thermoelectric Cooler (TEC) on its application in the portable refrigerator. Much research conduct to achieve the optimal performance of the thermoelectric cooling system. Kuan Chen, Scott B.Gwilliam, [1] analyzed the rate of heat transfer and the efficiency of thermoelectric cooling systems in the TE refrigerators system for air conditioning application with a heat exchanger. It found that if a TEC cooling system incorporates a heat exchanger, a non-uniform current distribution should be used to achieve the maximum efficiency with the lowest cold fluid temperature.

Heng Ren [2], Mayang Aswathi, and KV.Mali [3] showed that the heat sink with a thicker base has lower temperatures. Hamdi E.Ahmed [4] has reported that that ribbed plate-fin heat sink provides a thermal performance of 1.55 times greater than Plate flat Heat sink. S.M.Pouryoussefi and Y, Zhang [5] showed that free-stream air velocity on the heat sink has a significant effect on the thermal and hydrodynamic performance of the system. With increasing free stream velocity, the heat transfer coefficient increases. D.Astrain, J.G.Vian, J.Albizua [6] research indicates that the coolant temperature thermoelectrically heat sink with inner fins and fan, resulting in a lower temperature in comparison with that without fins and fan. Denpog Soodphakdee, Masud Behnia, and David Watabe Copeland [7] explained that In general, the staggered plate-fin geometry showed the highest heat transfer for a given combination of pressure gradient and flow rate. Onoroh Francis, Chujuneke Jeremiah Lekwuwa, Itoje
Harrison Jhon [8], showed that for maximum efficiency, the temperature difference between source and sink is to keep to the barest minimum. Kennedy, Khairil Anwar dan Briand A.[15] investigated the influence of speed of the fluid at the cool side of TEC, which placed inside the cooler box. The investigation results show that the lowest temperature can reach the lowest speed of air. All of the studies mentioned above have shown that the heat sink on the hot side or cold side will dramatically affect the performance of the thermoelectric cooling system.

2. Thermoelectric Cooler Configuration

2.1 Thermoelectric Module
The working principle of the thermoelectric cooling machine is often called Thermoelectric Cooler (TEC) is to absorb heat in the cooler terminal through cold and heat terminal elements disposed on the thermoelectric. Absorption and heat dissipation caused by DC electric current flowing to a few pairs of P-type semiconductor cells (low energy) and n-type (high energy). Transfer electrons from high energy to low energy showed in figure 1.

![Figure 1. Thermoelectric modul [3]](image-url)

The temperature difference on the terminal side of cold and heat terminal thermoelectric elements caused by the movement of electrons flowing from the p-type semiconductor in which a lack of energy and absorbs heat to supply energy to the cold side. The flow of electrons to n-type occurs when n-type semiconductors have excess electrons, the electrons will be discharged into the surrounding air in the form of heat and then move to p-type semiconductors.

Thermoelectric modules generally made from a variety of semiconducting materials such as Bismuth Tellurium (Be-2 Te3), Plumbum Tellurium (PbTe), and Silicon Germanium (SiGe. Bismuth Tellurium (Be-2 Te3) rod-shaped rod coated with a thin ceramic heat-absorbing function of the cooler and releases it into the air. In this study, thermoelectric used is Bismuth Tellurium (Be-2 Te3) type TEC1-12715 with 164.2 Watt maximum cooling power.[9].

2.2 Hot side of thermoelectric
The heat sink is one of the important components in the thermoelectric cooling system, to heat dissipated. The liquid-cooler heat sink has a better performance than forced air convection heat sink [9] [10], for that reason, this study uses a 50x50x3 mm, commercial liquid-cooler copper heat sink as shown in figure 3.
2.3 Cold Side of thermoelectric
In the thermoelectric cooler refrigerator, heat sinks used to accelerate the rate of heat absorption from the room to the cold side of the thermoelectric module. Aluminium Plate-fin heat sink with a fan was mostly used in the form of circulating air into the sink, as shown in figure 4.4.
generally provides the best performance since the air blown into the face of the heat sink creates more considerable turbulence resulting in improved heat transfer. For optimum performance, the housing of an axial fan should mount a distance of 8-20mm (0.31-0.75") from the fins.

![Air Flow Diagram](image1)

**Figure 5.** Forced Convection Heat Sink System Showing Preferred Air Flow [14]

In this study, the aluminium ribbed flat-plate fin heat sink commercial with dimensions 20x12x3.5 cm was used as a heat sink, with the base thickness 5 mm. The total ribbed fin on the heatsink is 12 units, the fin thickness 3 mm in the base and 1 mm at the tip of the fin, such as the following figure 6.

![Aluminium Ribbed Plate Fin Heat Sink](image2)

**Figure 6.** The Aluminium ribbed plat-fin cold sink

2.4 **The Cooler Box**

This work is an initial study to create a portable cooler box for fishermen and small traders in Indonesia for that, the cooler must be inexpensive but still lightweight and efficient. The most widely used cooler made of Styrofoam cooler boxes with dimensions 75 x 42 x 32 cm, uniform wall thicknesses of 3 cm, this cooler box is used in the present study.

![Styrofoam Cooler Box](image3)

**Figure 7.** Styrofoam cooler box
2.5 Calculation and data analysis.
The performance of thermoelectric modules can be known from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because the thermal conductivity of the thermoelectric material, and a portion of the total Joule heating effect generated by the electric current to thermal resistance. From the energy equilibrium is obtained:

Seebeck Coefficient :
\[ \alpha = 2 \cdot \alpha_m \cdot N \] (1)

Seebeck coefficient of device (V/K):
\[ \alpha_m = \alpha_0 + \alpha_1 T_{ave} + \alpha_2 T_{ave}^2 \] (2)

Thermal conductivity
\[ K = 2 \cdot K_m \cdot N \cdot G \] (3)

Device thermal conductance
\[ K_m = K_0 + K_1 T_{ave} + K_2 T_{ave}^2 \] (4)

Device electrical resistance
\[ R = \frac{2 \cdot \rho \cdot N}{G} \] (5)

Resistivity
\[ \rho = \rho_0 + \rho_1 T_{ave} + \rho_2 T_{ave}^2 \] (6)

Heat Absorbed at the Cold Side of TEC:
\[ \dot{q}_c = 2N \left[ \alpha_m \cdot I \cdot T_c - K_m \cdot \Delta T_p \cdot G - \left( \frac{I^2 \cdot \rho}{2G} \right) \right] \] (7)

Heat dissipated on the hot side of TEC:
\[ \dot{q}_h = 2N \left[ \alpha_m \cdot I \cdot T_h - K_m \cdot \Delta T_p \cdot G - \left( \frac{I^2 \cdot \rho}{2G} \right) \right] \] (8)

Input power of TEC :
\[ P_{in} = I^2 \cdot R \] (9)

Energy balances obtained:
\[ \dot{q}_h = \dot{q}_b + P_{in} \] (10)

Figure of merit (Z) is a combination of three types of parameters on the thermoelectric properties and influence the cooling effect and indicate the quality of thermoelectric elements.
\[ Z = \frac{\alpha_m^2}{\rho \cdot K_m} \] (11)

Coefficient of Performance (COP) of a thermoelectric cooling system that can be calculated from a comparison of the amount of heat absorbed at the cold side to the input power :
\[ \text{COP} = \frac{\dot{q}_c}{P_{\text{in}}} \]  \hspace{1cm} (12)

Figure 8. Energy balance of the thermoelectric cooler [15]

3. Experimental Setup
This study conducted by the experimental method, the thermoelectric system, which consists of a liquid-cooled heat sink, a TEC1-12715, and air forced heat sink with a fan on the cold side of TEC. The DC fan, 12V-0.33A, with dimension 12 x 12 cm, was mounted at the center of the fin of a heat sink. The blade fan diameter is 11.9 cm, as shown in Figure 9. The direction of Airflow circulation varying with two variations, based on fan and heat sink, by Blowing from into the heat sink (BHS) and Sucking from the Heat sink to the room (SHS), illustrated in Figure 10. The speed of airflow was measured with a digital anemometer and varying by adjusting the fan rotation using a resistor that generates airflow speed through the fin is 1.4; 2.0 and 2.9 m/s.

Figure 9. Air Heat sink fith fan

The digital thermometer with data logger is used to measure and record temperature changes on the ambient temperature, inbox temperature, heat sink temperature, temperature cold side of the TEC (Tc), the hot side of the TEC temperature (Th), Air temperature in to the fan (Tin), Air temperature out the fan (Tout), and water temperature on the water batch (Tw). Input current and voltage of TEC measured by using the dual digital volt-ampere meter. All data recorded every minute for 100 minutes on each test variation, to verify the data, testing for each variation speed and direction of the airflow carried out three times.
4. Result and Discussion

Investigation results shown for all three combinations of airflow and fan modes on heat sink influenced the cold box temperatures. At the same speed of airflow, the SHS mode results in a lower temperature of cooler than BHS mode, as shown in figure 12. The lowest temperature of the cooler box is 11°C; it has achieved at a speed of airflow 1.4 m/s on SHS mode. The lowest cooler box temperature achieved at a speed of airflow 1.4 m/s on SHS mode.

The pattern of temperature degradation of fluid across the heat sink between SHS mode and BHS mode is different. As shown in figure 13 and figure 14 The temperature degradation on BHS mode has relative small than the SHS mode. These results indicate the difference in the flow pattern of fluid on the heat sink. The moderate fluid flow in the heat sink at SHS mode will significantly decrease the temperatures at the cooler side of TEC and will also reduce the cooler temperature, as shown in figure 15.

The speed of airflow will also reduce temperature ($\Delta T_{\text{in-out}}$). The most significant reduction of air circulation temperature has reached 2°C at 1.4 m/s of airflow with SHS mode of fan. These results have shown the effects of air circulation along the fin will influence heat transfer on the heat sink.

Based on the law of mass conservation, the mass of air entering the fan with moderate speed and will be increased suddenly by the rotor. According to the previous study, the
pattern of exhaust flow of axial fans might increase the potential of backflow [16]. The value of coefficient convection heat transfer $h$ generally varies along the fin as well as its circumference, and the value at one point is strongly affected by the fluid motion at that point. The amount of $h$ is usually much lower at the fin base than at the fin tip because solid surfaces restrict the fluid flow near the bottom, which severely disrupts fluid motion. The fluid near the fin tip has a little contact with a solid surface and resulting in slight resistance to flow. The overall heat transfer will be lower when the value of $h$ is lower [12], from this, it can seem that in SHS mode velocity of air in the heat sink relatively slower than the BHS mode, more air can touch the fin surface and results in the higher release of heat from the air.

Figure 12. Coolbox room temperature

Figure 13. Circulation air temperature difference

Figure 14. Circulation air temperature
The amount of heat absorption by TEC has shown in figure 16. The highest heat absorbed at the speed of air 2.9 m/s on BHS mode. Generally, the heat absorption on BHS mode is higher than SHS mode. These results are affected by the temperature degradation of cooler. Degradation of temperatures on SHS mode is occurring rapidly, and then the heat absorbed by cooler will be lower. This condition is also influenced the low infiltration of heat from outside of the cooler. As results, the cooler temperatures on BHS mode are remaining higher than the SHS mode.

Dissipated heat and power input by TEC is relatively similar for all of the variations of flow direction and speed of air, as shown in figure 17 and figure 18. The reason is the temperature and flow rate of coolant are constant. The coefficient of performance of thermoelectric not significantly
changed for all different combinations of fan modes and speed of airflow. The discrepancies of COP are only between 0.5 and 0.56, as shown in figure 19.

Figure 18. Input Power of TEC

Figure 19. COP average

5. Conclusion
The investigation results that temperature degradation inside the cooler of the thermoelectric system with ribbed plate-flat heat sink at the cool side of TEC, influenced by velocity and circulation direction of airflow at the cold side of TEC. The air circulated with SHS mode at low speed resulting in the lowest temperature of cool box. The heat dissipated from TEC more affect the power system input of TEC.

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