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Performance of TEC Cascade on Input Voltage Variations in Fish Cooler Box

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Abstract

The refrigeration system used to meet the needs of human life can be in the form of a thermoelectric cooler (TEC). Due to its small volume, environmental friendliness and several other advantages, TEC can be widely applied such as in fish cooler box. In this study, the cooler boxes used had dimensions of 290mmx 205mm x 254 mm and were given twelve stacked 3 TEC modules with varied DC voltages. The purpose of this study is to determine the voltage that can provide the best TEC performance. This performance will be indicated by the Coefficient of Performance (COP) value of each voltage variation. The experimental results show that the best performance of the TEC is at 42 Volts. The lowest temperature achieved during the experiment was 7.74℃ on the cold-side.

Keywords: Coefficient of performance; cool box; thermoelectric cooler

1. Introduction

Fish is the most perishable food source. The presence of microorganisms causes the speed of the decomposition process in fish so it needs to be preserved, and the cooling system is one method of preserving fish [1]. Cooling machines are currently being used more and more by humans to meet the needs of life [2]. Cooling systems are used to reduce heat both in manufacturing processes [3], energy conversion, environment [4], and food processing [5] Various types of cooling systems that are currently commonly used are air-based cooling systems; and liquid-based cooling systems; Phase Change Material (PCM) based cooling systems [6] and thermoelectric based cooling systems [7].

Thermoelectric cooler (TEC) is a module that can be used for cooling systems. TEC can convert electrical energy into temperature differences directly by using the Peltier effect [8-11]. TEC consists of two different types of semiconductors, namely P and N type semiconductors which are connected via electrodes [12] as shown in Fig. 1. Cooling TEC is an environmentally friendly cooling that can be used as a heat pump in solid form to increase the cooling energy generated. TEC cooling can be directly used using direct current (DC) electricity without using refrigerants and does not cause harmful effects to the environment [13-15].

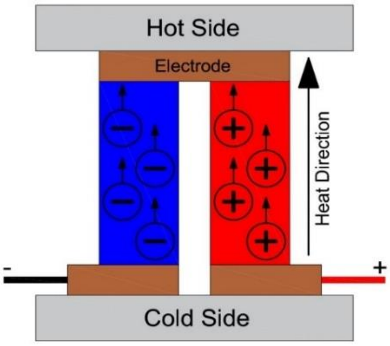

Figure 1. Sketch of General thermoelectric consisting of two ceramic substrates that serve as the foundation and electrical insulation for an n-type (left) and p-type (right) semiconductor element

In the TEC module, electrons in the n-type semiconductor and holes in the p-type semiconductor both move away from the cold-side to the hot-side when external DC power is applied [16]. The movement of electrons and holes in the two semiconductors then carries heat from the cold to the hot sides of the TEC [17].

TEC can be widely applied because it has many advantages, including small volume, does not cause noise, is environmentally friendly, and does not have mechanically moving components [8, 18]. Apart from these many advantages, the low performance coefficient of TEC is a technical obstacle that can limit its widespread application [19]. The TEC installation can be configured in a stack that forms a multi-stage thermoelectric module as shown in Fig. 2 [17].

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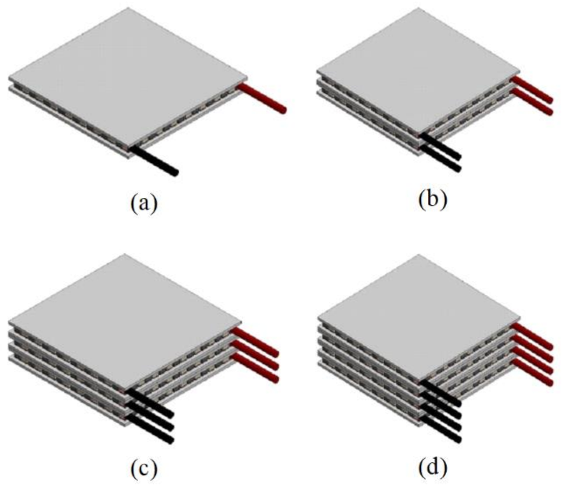

Figure 2. The thermoelectric cooler modules with the configuration of (a) single-module; (b) double modules cascade ; (c) triple modules Cascade ; (d) quadruple-modules cascade

As a result of the development of manufacturing technology and high quality raw materials, commercial TEC modules have a long service life of around 100,000 hours [20]. However, in its application, it is possible for the TEC to damage more quickly. This is indicated by a decrease in the cooling capacity of the TEC or ΔTmax which is below the specified criteria, and an increase in the TEC electrical resistance, usually the range of increasing the TEC electrical resistance is 5% or more [20]. TEC1-12706 is a standard size TEC which has 127 arrangements of n-type and n-type semiconductors with a maximum current that can be consumed of 6 Amperes where this type of TEC will be used in this experiment [20].

In a comprehensive review of thermoelectric cooling parameters and performance for specific refrigeration systems, Thiangchanta et al. [21] conducted experiments using a thermoelectric with a vacuum wall and can lower the temperature by about 15℃. Haryanti and Yulianti [2] made a prototype cooling system using two TECs installed in parallel and capable of lowering the temperature of a certain room to 22℃. The experimental results of He et al. [22] where experiments were carried out using a thermoelectric which is known to have a cold-side close to 15℃. Mirmanto et al. [23] concluded that the position of placing the TEC position on the box can affect the cooling process of the cooler box.

The lowest temperature achieved from previous studies is in the range of 15℃. For this reason, this latest research intends to improve the performance of the TEC which will be used in cooler boxes by attaching three modules arranged in a cascade. The performance that will be measured is the COP of the experimental set up.

2. Research Method

2.1. Installation of experimental tools

Figure 3 shows the details of installing the thermoelectric device in the cooler box. Experimental equipment includes an aluminum box covered with styrofoam (290 x 205 x 254 mm), twelve TEC modules used in this experiment, heatsinks, fans, power supply units, and temperature data acquisition as well as a multimeter to measure voltage, current, and resistance. electricity. All contacts between the aluminum box, thermoelectric cooler, and heatsink are arranged as well as possible so that they have minimum thermal resistance using thermal paste.

The cooler box material is made of aluminum with a thickness of 1 mm and wrapped with a styrofoam thermal insulator with a thickness of 20 mm. Twelve TECs with type TEC1-12706 are used as cooling devices with a size of 40 mm x 40 mm x 3.8 mm. The working voltage of the TEC varies from 38 volts, 42 volts and 46 volts with a total electrical resistance of 40.2 Ω TEC. A multimeter is used to measure the power supplied to each Thermoelectric module. A heatsink is attached to the hot-side of the thermoelectric module to help disperse heat to the environment. Meanwhile, the cold-side of the thermoelectric module is mounted on the wall of the aluminum box. DC fans are used to circulate air through the heatsink to help distribute heat to the ambient air.

2.2. Experimental method

After DC power is supplied to the thermoelectric module, the hot-side of the thermoelectric releases heat and the cold-side of the thermoelectric absorbs heat. This happened simultaneously. The cold-side that is attached to the wall of the aluminum box will continue to decrease in temperature from the initial temperature. Due to conduction heat transfer, the temperature of the aluminum box will decrease resulting in a decrease in the room temperature in the aluminum box. After a certain time interval, the temperature of the thermoelectric cold-side will reach its lowest temperature and remain constant at that temperature as long as the electric voltage is still applied.

The electric voltage given to the thermoelectric module is set in three variations, namely 38, 42 and 46 volts. The thermoelectric modules are arranged in series in an electric circuit and work in series-parallel. The total thermoelectric modules used are 12 modules where 6 thermoelectric modules are placed on the left side of the cooler box, and the remaining 6 modules are placed on the right side of the cooler box.

The COP analysis of the cooler box is calculated from the heat absorbed on the cold-side of the TEC (Qc) and all electric power consumption (Pin) which can be written in Eqs. (1) and (2) [16] [24].

$$COP = \frac{Q_c}{P_{in}} \tag{1}$$

$$P_{in} = Q_h - Q_c \tag{2}$$

$$Q_c = \alpha I T_c - k\Delta T - 0{,}5 I^2 R \tag{3}$$

$$Q_h = \alpha I T_h - k\Delta T + 0{,}5 I^2 R \tag{4}$$

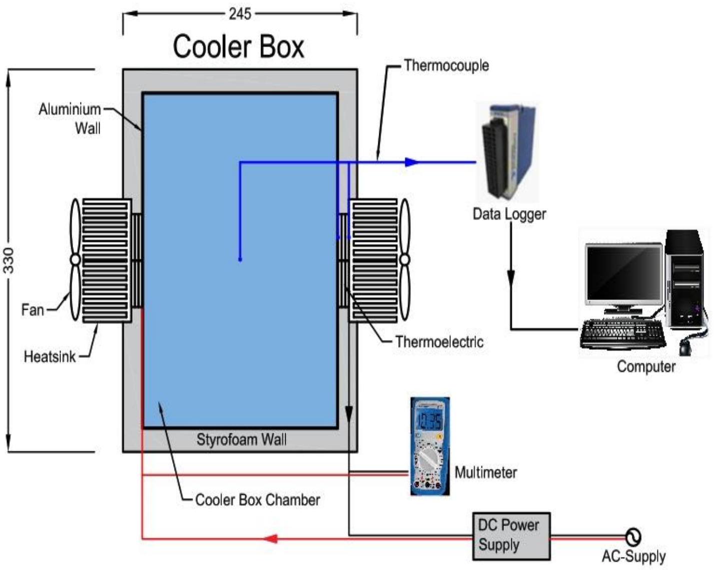

Figure 3. Experiment installation

Where α is the magnitude of the Seebeck coefficient; Th and Tc are the hot-side and cold-side TEC temperatures; R and I respectively represent electrical resistance and working electric current; k is the thermal conductance and Qh is the heat released by the hot-side of the TEC and is calculated using Eq. (4) [16, 24]. Qc is the cooling capacity of the Peltier module which will be calculated using Eq. (3) [16, 24].

Previously, experiments had been carried out with the same method but differed in the arrangement and number of TECs used. For installation of a single TEC module, four TEC modules are required to be used. two modules are placed on the left side of the coolbox and the other two modules are placed on the right side of the coolbox. TECs are arranged in series in an electrical circuit and work in parallel with a given voltage of 14 Volts. The average temperatures of the TEC cold-side, hot-side TEC and coolbox are 17.45℃, 29.85℃ and 18.97℃ with an average COP of 0.021. In the installation with two modules of TEC arranged in a cascade, a total of eight TEC modules have been used. Four modules are placed on the left side of the coolbox and the other four modules are placed on the right side of the coolbox. TECs are arranged in series in an electrical circuit and work in series-parallel with a given voltage of 28 volts. The average temperature of the TEC cold-side, TEC hot-side and in the cooler are 14.79℃, 35.89℃ and 16.82℃ with an average COP of 0.048. The difference in the electric voltage obtained from the given electric voltage is the total voltage supplied for each TEC of 3.5 Volts. So that by increasing the number of TECs used, the electric voltage supplied also increases to meet the needs of each TEC of 3.5 Volts.

3. Results and Discussion

3.1. Cold-side and hot-side temperatures

Figure 4 shows the temperature changes on the cold and hot-sides of the TEC during operation. The operating time lasts 480 minutes. The cold-side temperature is the temperature of one side of the TEC module which absorbs heat because the heat on that side is pumped to the other side of the TEC module when electricity is applied so the temperature is lower. This cold-side then absorbs heat in the coolbox so that the coolbox temperature decreases. The temperature of the hot-side is the temperature of one side of the TEC which releases heat because this side receives heat pumped from the cold-side so that the temperature is higher.

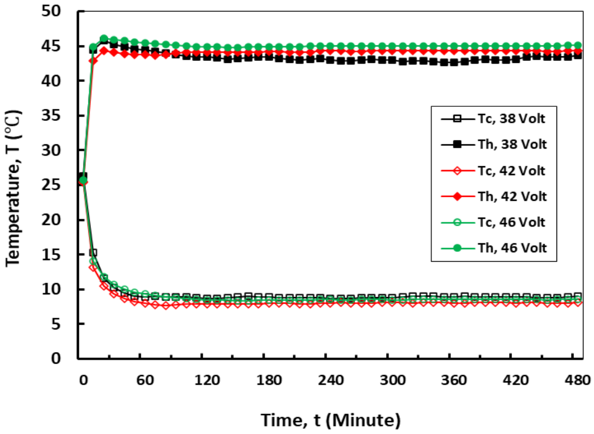

Figure 4. History of Tc and Th of TEC modules

Experimental data shows that the voltage variation of 42 Volts has a lower TEC cold-side temperature compared to the voltage variations of 38 Volts and 46 Volts. However, within the first 80 minutes of system operation, the cold-side temperature of the TEC at a working voltage of 38 volts was lower than the cold-side temperature at a working voltage of 46 volts. The lowest temperature on the cold-side occurs at 42 volts, which is 7.74℃. The temperature difference on the cold-side of the TEC when a voltage of 42 volts is applied at the 480th minute is 0.85 ℃ for a variation of 38 volts, and 0.45 ℃ for a variation of 46 volts.

The supply of 46 volts produces a hot-side temperature that is higher than the supply of 42 volts and 38 volts. The average temperature difference from 46 volts to 42 volts

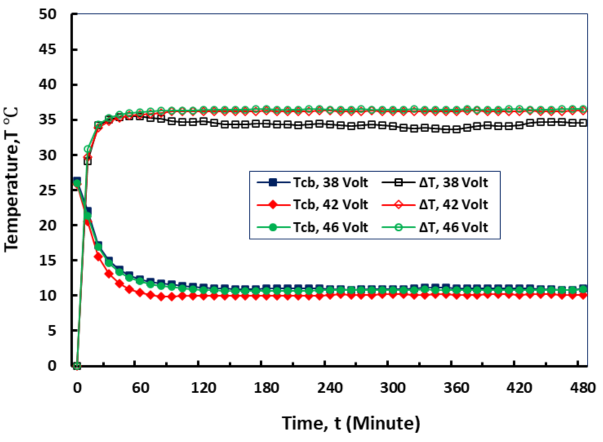

Figure 5. History of Tcb and ΔT of TEC modules

and 38 volts is 0.73℃ and 1.63℃ respectively. The temperature of the hot-side at 480 minutes for each given working voltage is 43.62℃ at 38 volts, 44.35℃ at 42 volts, and 45.12℃ at 46 volts. Thus, as the greater the applied voltage, starting from 38 volts, 44 volts and 46 volts, it will produce a greater temperature difference even though there is a decrease in temperature on the cold-side. This is due to the consistent rise in temperature on the hot-side as the applied voltage increases.

3.2. Coolbox temperature and ΔT

Figure 5 shows the temperature change in the coolbox and the temperature difference between the cold-side and the hot-side of the TEC during system operation time. The supply of 42 volts produces a lower coolbox temperature than the supply of 38 volts and 46 volts. The average temperature difference from 42 volts to 38 volts and 46 volts is 1.05℃ and 0.82℃ respectively.

The lowest temperature achieved by the coolbox was 9.89 ℃ which was achieved in the 80th minute when the TEC module was supplied with an electric voltage of 42 volts. After that, the temperature in the coolbox increased again and fluctuated slightly with a temperature change range of ±0.3℃. The fluctuation range is not that large so that the coolbox temperature at 80 to 480 minutes can be stated to be in a fairly stable condition.

The temperature difference at 46 volts gives a higher value when compared to the temperature difference at 42 volts and 38 volts. The average temperature difference at 46, 42, and 38 volts is 35.50℃; 35, 23℃; and 33.60℃. Each additional applied voltage produces a higher temperature difference. This happens because of the Seebeck effect where the voltage is directly proportional to the difference in temperature difference. This means that if the electric voltage increases, so does the difference in temperature difference and vice versa.

3.3. Heat absorbed on the cold-side (Qc)

Figure 6 shows the ability of the cold-side of the TEC module to absorb heat during system operating time. Data on the ability of the cold-side of the TEC module to absorb heat is obtained from the calculation results based on Eq. (4). Figure 6 also shows that by providing 46 volts of electricity, the power to absorb heat on the cold-side of the TEC module is higher than that of 42 volts and 38 volts. Even so, the temperature of the cold-side of the TEC module at 42 volts is lower than at 46 volts as shown in Fig. 4. This happens because of the ability of the cold-side of the TEC module to absorb heat (Qc) is affected by the electricity current that passes through the TEC module. for input voltage 38 volts, the electric current is 0.9 amperes. Meanwhile, for input voltage of 42 volts and 46 volts, the electric current are 0.99 amperes and 1.08 amperes. Thus, the highest value of the ability of the cold-side of the TEC module to absorb heat is achieved by varying the voltage of 46 volts.

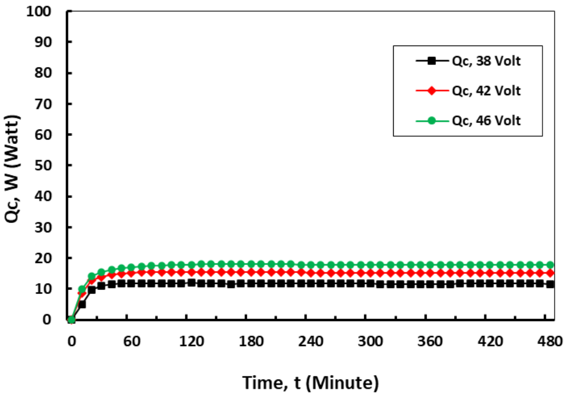

Figure 6. History of Qc on the cold-side of TEC modules

3.4. Heat released on the hot-side (Qh)

Figure 7 shows the value of heat released on the hot-side of the TEC module during system operating time. Data on the value of heat released on the hot-side of the TEC module is obtained from the calculation results based on Eq. (3). It can be seen in Fig. 7, that when the supply voltage is 46 volts, the hot-side of the TEC module releases more heat to the environment compared to the supply of 42 volts and 38 volts. This happens because the temperature of the hot-side of the TEC module at a voltage of 46 volts is higher when compared to the temperature of the hot-side of the TEC module when input voltage of 42 volts and 32 volts are applied as shown in Fig. 4. In addition, this is also affected by the electric current flowing passes through the TEC module when mains voltage is applied. At a voltage of 38 volts, the electric current is 0.9 amperes, while at a voltage of 42 volts and 46 volts, the electric current are 0.99 amperes and 1.08 amperes respectively. So that the greater the voltage supplied, the greater the heat value released by the hot-side of the TEC module to the environment.

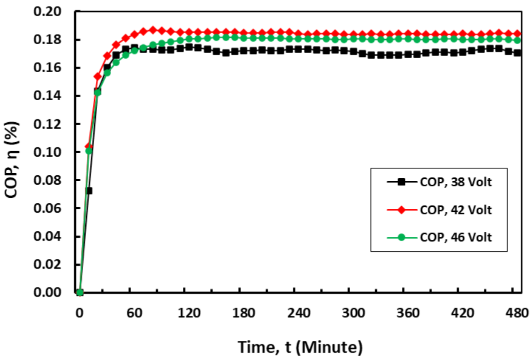

Figure 7. History of Qh on the cold-side of TEC modules

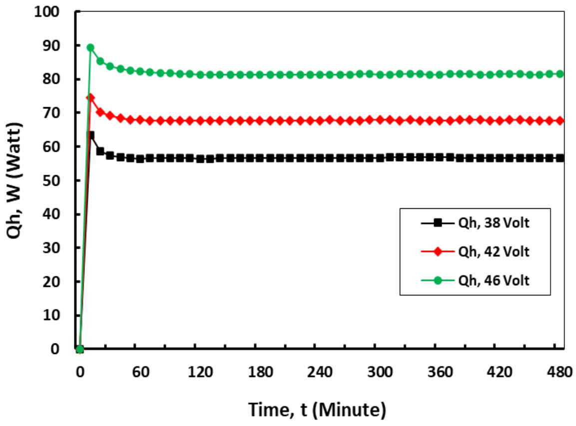

Figure 8. History of COP of TEC modules for three variation input Voltages

3.5. Coefficient of performance (COP)

The COP of the TEC module based on the given electric voltage is shown in Fig. 8. This COP is one of the parameters to measure the performance of the TEC module in cooling. The higher the COP value indicates the better the performance of the TEC modules. This is influenced by the cold-side temperature or ΔT generated by the TEC module when an electric voltage is applied. The lower the cold-side temperature or the greater the ΔT obtained by the TEC module, the higher the COP value.

In Fig. 8. it is shown that the best performance of the TEC module is given by a variation of the electric voltage of 42 Volts during the operating time of the system, amounting to 0.187. This occurs due to the low temperature of the cold-side of the TEC module at an input voltage of 42 Volts as shown in Fig. 4.

For an input voltage of 38 volts, the performance of the TEC module is not that good and fluctuations occur. The low COP value indicates the lack of ability of the cold-side of the TEC module to absorb heat and the low temperature difference between the cold-side and the hot-side of the TEC modules. While the COP value for a system with an input voltage of 46 Volts looks quite stable compared to 38 Volts. However, because the value is lower than the input voltage of 42 volts, the performance of the TEC module for an input voltage of 46 volts is no better than the performance of the input voltage of 42 volts even though the temperature difference between the hot-side and the cold-side of the resulting TEC modules is greater.

4. Conclusion

This experiment was carried out with a system operating time of 480 minutes. The system is a cooler box using a thermoelectric cooler module as the cooling medium. The thermoelectric modules are arranged in series in an electrical circuit, and work in series-parallel with a total of twelve TEC modules used. The best cooling is shown by the input voltage variation of 42 volts. At an input voltage of 42 volts it produces a lower cold-side temperature compared to other variations. However, the temperature difference that occurs between the hot-side and the cold-side of the TEC module at an input voltage of 46 volts is greater than the input voltage of 42 volts and 38 volts. The cold-side temperature and the temperature difference between the hot-side and the cold-side of the TEC module are two parameters that significantly influence the COP where the value indicates better TEC module performance. From the results of data processing, it was found that the COP value at the input voltage of 42 volts is 0.187. higher than the input voltage of 46 volts and 38 volts.

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