Development of Thermoelectric Refrigeration System and The Control System Based on Arduino Uno

Eddy Erham[1, a)], Ary Surjanto[1)], Rizki Maulana [1)], Nur Khakim[1)], and Niedha Mulya Nurshandy[1)]

[1]Department of Refrigeration and Air Conditioning, State Polytechnic of Bandung (POLBAN), Indonesia

Corresponding Author's email: eddy.erham@polban.ac.id

Abstract. Thermoelectric refrigeration system is expected to provide the best choice when compared to conventional refrigeration systems. However, unfortunately the performance is still very low. In this research was developed a thermoelectric refrigeration system and control system based on Arduino Uno. For this purpose was observed the effect of expanding the heatsink and multiplication of several thermoelectric cells on the temperature of the cold junction, cabin and COP. For this development was designed the system consisting of two parts, namely mechanics and electronics. The mechanical design includes the calculation of the cooling load and the selection of components and constructing the system. While the electronic design includes the design of control and monitoring systems. The design results show that for both expanding the heatsink-4 (HS-4) and multiplication of the HS-4 were obtained the minimum cold junction temperature, minimum cabin temperature, COP, energy consumption by -1.36º C, 6.23º C, 0.47 , 0.31 kWh and -3.64ºC, 1.93ºC, 0.47, 1.23 kWh, respectively. The result also shows that the cold junction temperature is lower than the previous research temperature which ranges from 2.3 ^{0}C to 10.5 ^{0}C. In addition, the obtained results are better than previous researches.

Keywords: Arduino Uno, cold junction, control system, heatsink, thermoelectric refrigeration system.

1 INTRODUCTION

The thermoelectric refrigeration system is an alternative refrigeration system. This system does not use refrigerant as in vapor compression refrigeration systems so it is more environmentally friendly. The working principle is based on the Peltier effect, when an electric current flows, then at the junction of two different materials will occur heat absorption and heat release[1].

In connection with the thermoelectric refrigeration system, research has been carried out to use the TEC1-12706 (bismuth-tellurium) type module. The results show that the cold junction temperature was 2.32ºC, the hot junction temperature was 40.7ºC and the COP was 0.26 [2]. In addition, similar research shows that the cold junction temperature was 4.73ºC, the hot junction temperature was 35.6ºC, the COP was 0.204 and the cabin temperature was 12.13ºC [3].

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Furthermore, research has also been carried out on thermoelectric refrigeration systems equipped with Arduino. The results showed that the cold junction temperature was 6.23ºC, the hot junction temperature was 34.07ºC, the cabin temperature was 10ºC, and the COP was 0.5 [4].

Apart from the three studies above, there are also several new developments in thermoelectric refrigeration research. First, performance observations had been conducted from the aspect of different cooling load conditions. The obtained results were that the COP varies from 0.17 to 0.26 and the coldest temperature that could be achieved was from 2.3 ^{0}C to 10.5 ^{0}C in 28 minutes, respectively [5].

Second, the observations had been also carried out from the aspect of optimizing operational conditions for thermoelectric refrigeration. The results show that the optimal voltages of the embedded Peltier element on wall of cabin, the outside fan of cabin and the inside fan of cabin that maximize COP were 12 V, 9 V and 3 V, respectively. The results also show that the COP decreased from 0.3351 to 0.011 while the cabin temperature changed from 20^{0}C to 18.2^{0}C [6]. Furthermore, an investigation had also been carried out on the parameters that affect the performance of thermoelectric refrigeration. When an electric current of 0.5 – 2 A was applied for 15 minutes, it was found that the lowest T_{cabin} decreased from 26.490C to 19.320C and the lowest $T_{cold\text{-}J}$ from 25.70 ^{0}C to 7.05 ^{0}C. In addition, the highest COP was 0.10 with a parallel connection [7].

Third, a cascade system consisting of eight thermoelectric modules had been designed to reduce the temperature of the fourteen liter cabin from 28.7°C to 3°C after 4 hours. Under the designed conditions, a COP of 0.34 was obtained [8]. Furthermore, a performance investigation had also been carried out from the aspect of the rate of decrease in cabin temperature. The results show that the temperature drop was from 20.8^{0}C to 20^{0}C with no-load conditions in 3.5 hours. Meanwhile, the temperature drop was from 23.6^{0}C to 20^{0}C under load conditions for 9 hours. While the COP was 0.85 [9].

Based on these literature sources, it can be concluded that the range of parameter values in the thermoelectric refrigeration system that can be achieved at this time are T_{cabin} from 3 ^{0}C to 28.7 ^{0}C, $T_{cold\text{-}J}$ from 2.3 ^{0}C to 10.5 ^{0}C and COP from 0.011 to 0.34 and the used methods can vary. Besides low performance, the system is also usually not equipped with a control system. The results of some of these studies have not met the desired needs such as in a vapor compression system, so further research is needed to reduce cold junction and cabin temperatures and increase COP.

In this research was developed a thermoelectric refrigeration system and control system based on Arduino Uno was developed. For this purpose was observed the effect of expanding the heatsink on cold junction temperature and cabin temperature and COP. Then, it was designed a cascade system consisting of several thermoelectric modules and was used the best heatsink as a result of the expanded observations. After that, it was also observed the effect of installing several thermoelectric modules in the system on cold junction temperature and cabin temperature as well as COP.

The observations which were made leaded to performance that could be achieved. In this case, the more important role was the construction aspect of the system and its operational conditions. Meanwhile, the control system did not play a direct role in improving performance, but played a role in maintaining the temperature of the cabin and making it easy to change the setpoint when testing or observing data. In addition,

it makes it easier to develop the control system itself, for example, there are other parameters that need to be controlled so that performance increases.

The design of this thermoelectric cascade refrigeration system consists of two parts, namely mechanical design and electronic design. The mechanical design includes the calculation of the cooling load and the selection of components and constructing the system. While the electronic design includes the design of control and monitoring systems.

For the design of the control system as the controller was used Arduino Uno and as feedback was used a sensor. This Arduino was uploaded with the designed control system program. This program that was written in the Arduino IDE [10] does not only contain the on-off controller program, but also the display program and the others. Thus, Arduino can function as a controller. Meanwhile, the monitoring or display system was designed using an LCD screen and a laptop screen. The program was integrated with the controller program

2 DIGITAL CONTROL SYSTEM

The control system is a system that has a controller whose function is to correct response errors so that a response that is close to the desired input value is obtained [11]. Figure 1 shows a block diagram of a digital control system [12]. It is typical of this block diagram, the display block is connected to the controller and the setpoint is done from the control system program.

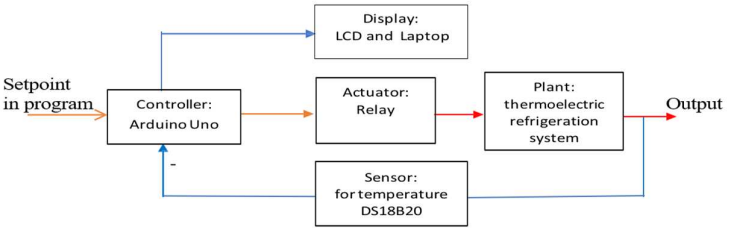

Fig. 1. Block diagram of digital control system.

2.1 On-Off Control System

The response of the on-off control system, $T_{set} = 22^0C$ and difference control of 2^0C, is shown in Figure 2 [11]. Setpoint is the desired input and its value is constant. With the control system, it is expected that the output value is the same as the desired input. But in fact, the output can only be close to the input value or almost the same. The output appears to fluctuate with respect to the setpoint. So, the output value is from [setpoint-(dif/2)] to [setpoint+(dif/2)].

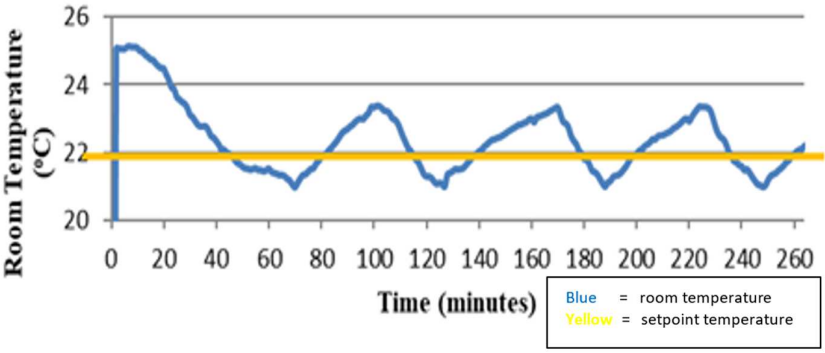

Fig. 2. Response of on-off control system.

3 DESIGN OF A THERMOELECTRIC REFRIGERATION SYSTEM

The design of this thermoelectric refrigeration system consists of two parts, namely the mechanical design and the electronic design. The mechanical design includes the calculation of the cooling load and the selection of components and constructing the system. While electronic design includes hardware and software design and its integration.

3.1 Mechanical Design

This design is more focused on the main components related to the mechanical system. The main components are the thermoelectric module and heatsink. It briefly explains the reasons for its selection. Meanwhile, other components can be traced and demonstrated directly in the construction of the mechanical system.

Fig. 3. Thermoelectric Module.

Figure 3 shows a thermoelectric module with type TEC1-12706. This module has a maximum voltage specification of 16 Volts, a maximum current of 6.1 Amperes and a maximum cooling capacity of 61.4 Watts. This thermoelectric module is the main component and functions to absorb heat on the cold side and dissipate the heat on the hot side. In this study, each module was given a voltage of 12 Volts and a current of 5 Amperes, so the thermoelectric module was chosen.

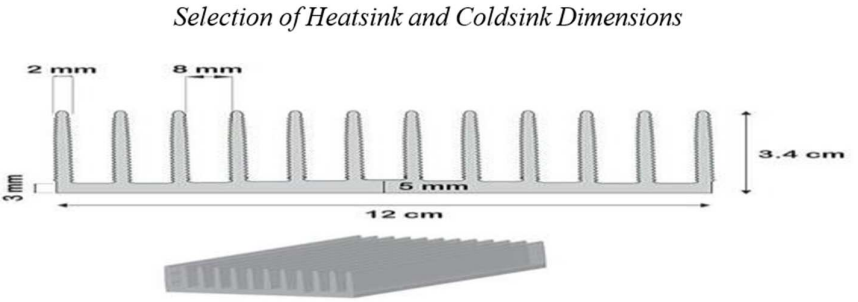

Fig. 4. Heatsinks.

Figure 4 shows the heatsink used to expand the heat transfer surface area, the presence of fins will increase the heat transfer area. The coldsink, which looks like a heatsink and is not pictured, is made of pure aluminum, with a coldsink length of 8.8 cm, width of 7 cm and thickness of 3.6 cm. While the heatsink is made 4 wide variations, namely by varying the length of each 8 cm, 10.6 cm, 13.3 cm and 26.6 cm. Meanwhile, the material, thickness, width are the same, namely aluminum, 3.5 cm, 12 cm, respectively. This is done in order to analyze the influence of the heatsink area on system performance.

Mechanical System Construction

Figure 5 shows the construction of the designed thermoelectric refrigeration system [13]. The cabin measures 17 cm long, 17 cm wide and 30 cm high. The material used is an aluminum plate with a thickness of 1 mm, insulation using polyurethane with a thickness of 3 cm and Armaflex insulation with a thickness of 1.4 cm. This cabin serves as a place to cool canned beverage products. This product has a height of 11.5 cm and a diameter of 6.5 cm, so that the cabin can accommodate 2 canned drinks. Meanwhile, the data table of mechanical system design can be seen in Table 1. This data is used to calculate the total cooling load and to construct this thermoelectric refrigeration system.

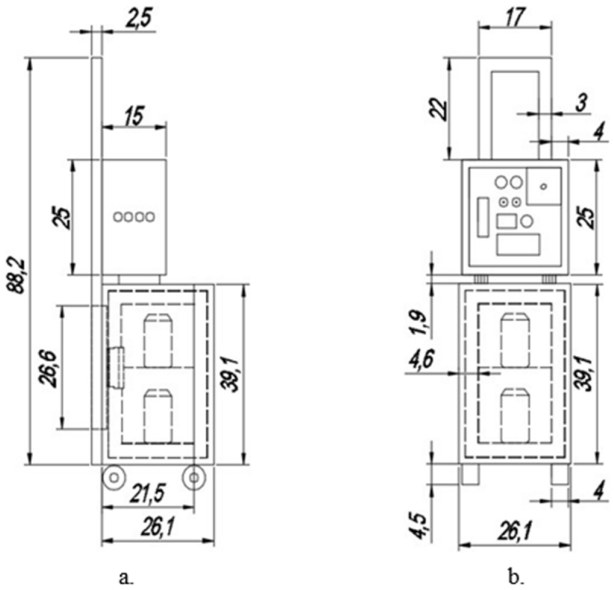

Fig. 5. Construction of a thermoelectric refrigeration system: (a). Side view. (b). Front view.

Table 1. Design Data.

Data	Dimensions
Cabin Dimensions *(length x width x height)*	17cm x 17cm x 30cm
Wall thickness	4.6 cm
Wall construction	Alumunium 0.1 mm, Polyurethane 3 cm, Alumunium 0.1 mm, Armaflex 1.4 cm
Environmental temperature	27ºC RH 60%
Product Initial product temperature	Canned drink 640 ml (2 @320ml) 25ºC
Designed cabin temperature	7 ± 1ºC
Cp of air	4.195 kJ/kg °C
Cp of can	0.91 kJ/kg °C
Weight of canned drink Power supply for thermoelectric module Power supply for Arduino Uno Power supply for sensor DS18B20 and Fan, respectively	0.0032 kg (2 @0.0016) 12 Volt DC, 5 Ampere From 5 Volt to 9 Volt DC 5 Volt DC and 12 Volt DC, 2 Ampere
Area of heatsink-1(HS-1), HS-2, HS-3, and HS-4, respectively	8x12, 10.6x12, 13.3x12, and 26.6x12 cm^2
Area of cold-sink	8.8 cm x 7 cm

3.2 **Hardware Design**

This design is more focused on designing the main components related to the control system. The main components are Arduino Uno and sensors. Meanwhile, the other components are shown directly with their connection paths to Arduino which can be

traced through the overall hardware circuit. Figure 6 shows the overall hardware circuit. This circuit consists of several integrated circuits, such as the DS18B20 sensor circuit, 4 channel relay, 16x2+I2C LCD and Arduino Uno. It also shows its connection to the thermoelectric refrigeration system.

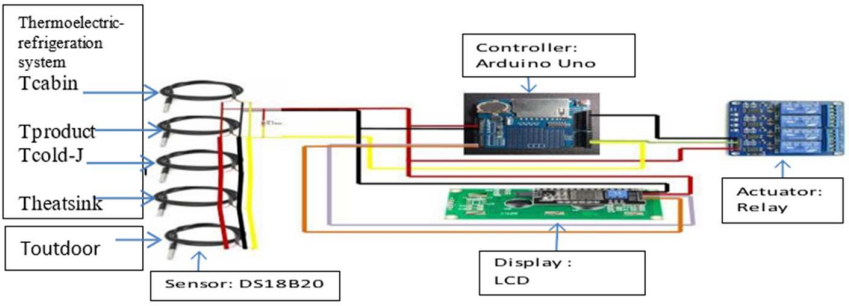

Fig. 6. The overall hardware circuit and its connection to thermoelectric refrigeration system.

3.3 Software Design

The program design is carried out based on the flowchart shown in Figure 7. This flowchart consists of two main parts. The first part contains the logic for keeping the refrigeration cabin temperature to be constant. By turning on or off the compressor. Second, it is also equipped with the design of a monitoring system program using an LCD or laptop screen.

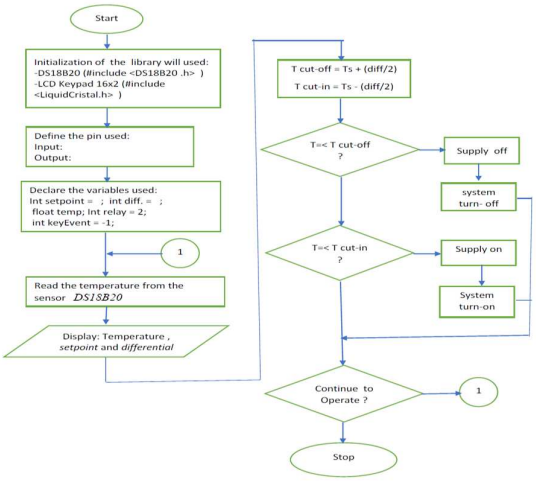

Fig. 7. Flowchart of control system and monitoring.

3.4 Equations for Analysis

To analysis performance of thermoelectric refrigeration system in the next section it will be calculated COP and electrical power with equations as follows :

COP equation

The coefficient of performance or often abbreviated as COP of a thermoelectric refrigeration system is the ratio of the amount of absorbed heat to the input power [14].

$$COP = \frac{Qc}{P} \tag{1}$$

Amount of Absorbed Heat

The way to calculate the amount of absorbed heat on the cold side is to take into account all thermal energies such as the Peltier effect, conduction heat transfer, and joule heating, therefore the energy balance equation for heat absorption can be written as follows:

$$Qc = \alpha ITc - \frac{\Delta T}{\theta} - \frac{I^2R}{2} \tag{2}$$

where α is Seebeck coefisien (V/K), I is electrical current (A), Tc is cold junction temperature (K), ΔT is temperature difference (K), θ is thermal resistance (K/W), and R is electrical resistance (Ω).

Input Power

When an electric current is applied to the thermoelectric, there is a temperature difference. If there is a temperature difference, the Seebeck effect occurs [14]. Therefore, the voltage on the thermoelectric when an electric current flows can be written as follows:

$$V = IR + \alpha\Delta T \tag{3}$$

So the amount of input power can be written as follows :

$$P = (IR + \alpha\Delta T).\ I \tag{4}$$

Note that V and I are measured using measuring instruments that are not permanently installed in the thermoelectric refrigeration system.

Regarding the relationship between heatsink expansion on electrical power and COP, it can be explained as follows. If the area of heatsink A is expanded, then the released heat into the environment will increase. This can be understood from the equation of convective heat transfer [15] as follows

$$Qr = h\,A\,\Delta T \tag{5}$$

Where Qr is the released heat into the environment, h is convective coefficient, A is area of heatsink, and ΔT is temperature difference.

This means that the electrical power (P) to remove this heat will decrease. Because with the expansion of HS, the released heat becomes easier. The heatsink temperature will also decrease so that heat transfer from the cold junction to the heatsink will increase. As a result, the cold-junction temperature (Tc) will decrease.

From the other side, the decrease in power is related to the decrease in electric current. Because electric current as a heat transfer medium will decrease as a result of easier heat transfer from the cold junction to the heatsink.

This is relevant to equation (4), if the electric current decreases, the electric power P will also decrease. Meanwhile, because Tc decreases, then the heat transfer from cabin to cold-junction or absorbed heat (Qc) will increase. Furthermore, if this condition is substituted into equation (1), then COP will increase. Thus, it can be concluded that the effect of HS expansion will increase COP and reduce electrical power consumption and reduce cold-junction temperature.

4 RESULTS AND ANALYSIS

4.1 Analysis of Heatsink Expansion Effect

To investigate the effect of Heatsink (HS) expansion on the performance of a thermoelectric refrigeration system had been carried out measurements for temperature of cold junction and cabin every 1 minute for 190 minutes. Increasing the expansion of HS was started from HS-1, HS-2, HS-3 to HS-4. When measuring, the cabin temperature was set to 7 ºC and different control of 2 ^{0}C. This means that T_{cabin} has a lower limit (cut out) by 6ºC and an upper limit (cut in) by 8ºC.

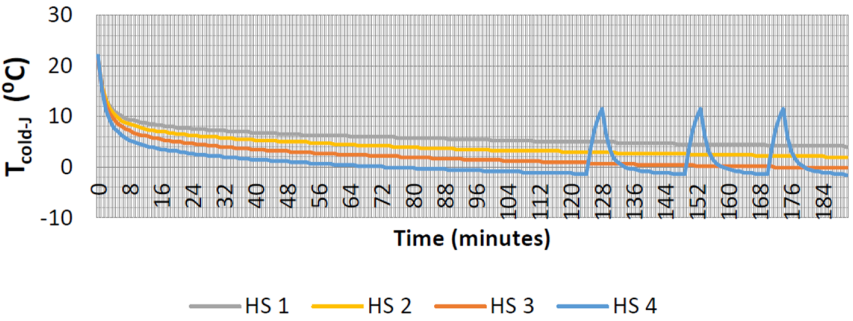

Fig. 8. Graph of cold junction temperature versus time with various heatsink areas.

Figure 8 shows that the cold junction temperature T_{cold-J} for all HS dimensions tends to decrease with time. If the HS dimensions are expanded, the T_{cold-J} will be lower. HS-4 tends to produce the lowest T_{cold-J} with fluctuations from -1.36 ^{0}C to 11.55 ^{0}C for cabin T_{set} of 7 ^{0}C , different control of 2 ^{0}C.

The T_{cold-J} for HS-4 is lower than in study [3] which has a T_{cold-J} of 4.73°C, and in study [4] 11°C. Likewise when compared to other studies, namely from 2.3 ^{0}C to 10.5 ^{0}C [1-9].

This result can be achieved due to improvements made to the heat dissipation system at the hot junction, by increasing the area of the heatsink. Furthermore, the effect of HS expansion on cabin temperature was observed.

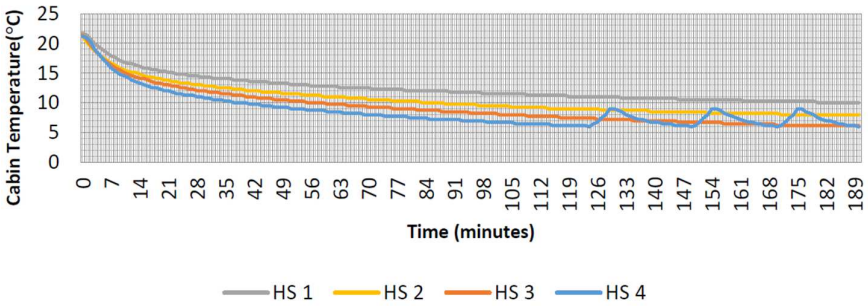

Fig. 9. Graph of cabin temperature against time with various heatsink areas.

Figure 9 shows that cabin temperature T_{cabin} for all HS dimensions tends to decrease with time. If the HS dimensions are expanded, the T_{cabin} will be lower. HS-4 tends to produce the lowest T_{cabin} with fluctuations from 6.23 ^{0}C to 9.01 ^{0}C for T_{set} cabin of 7 ^{0}C, different control of 2 ^{0}C.

The T_{cabin} for HS-4 in this study is lower than studies [3] and [4], namely 12.13ºC and 10ºC. The same thing applies when compared to other studies, namely from 3 ^{0}C to 28.7 ^{0}C [1-9].

4.2 Analysis of Heatsink Multiplication Effect

To further investigate the effect of HS expansion on thermoelectric performance, the four HS-4s were used simultaneously. Then, it were observed T_{cold-J} and T_{cabin} as before. During data collection, the cabin temperature was set at 3 ºC and different control of 2 ^{0}C so that T_{cabin} has a lower limit (cut out) by 2º C and an upper limit (cut in) by 4º C.

Cold junction temperature analysis

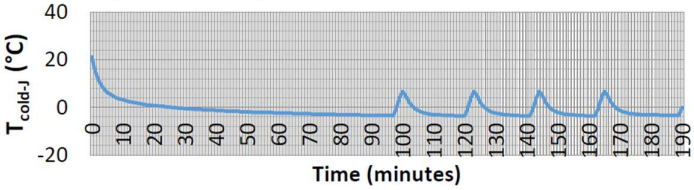

Fig. 10. Graph of cold junction temperature versus time.

Figure 10 shows that T_{cold-J} for the use of 4 pieces of HS-4 tends to decrease with time. T_{cold-J} fluctuates from –3.64 ^{0}C to 6.74 ^{0}C for cabin T_{set} of 3 ^{0}C , different control of 2 ^{0}C. Meanwhile, when using only 1 HS-4, the lowest T_{cold-J} that can be achieved is – 1.36 ^{0}C. So, T_{cold-J} for the use of 4 HS-4 pieces is lower than the previous studies, namely from 2.3 ^{0}C to 10.5 ^{0}C [1-9].

Cabin temperature analysis

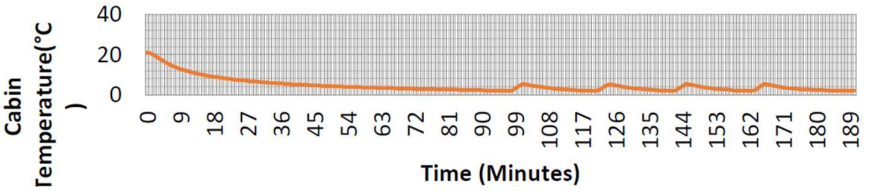

Fig. 11. Graph of cabin temperature versus time.

Figure 11 shows that T_{cabin} for the use of 4 HS-4 pieces tends to decrease with time. T_{cabin} fluctuates from 1.93 ^{0}C to 5.47 ^{0}C for cabin T_{set} of 3 C, different control of 2 ^{0}C. Meanwhile, when using only 1 HS-4, the lowest T_{cabin} that can be achieved is 6.23 ^{0}C. So, T_{cabin} for the use of 4 HS-4 units is lower than the previous studies, namely from 3 ^{0}C to 28.7 ^{0}C [1-9].

4.3 Analysis of the Effect of Expansion and Multiplication of HS on COP

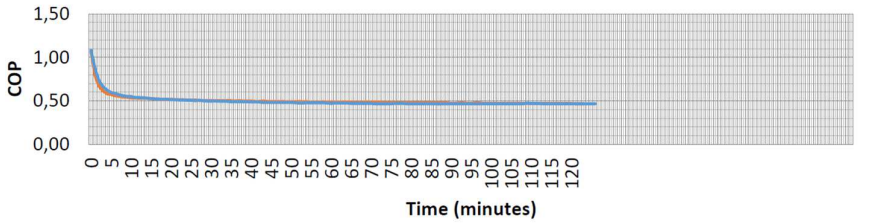

Fig. 12. Graph of COP versus time.

Figure 12 shows that the COP value for either a system with four times the HS-4 (thermoelectric cell) or a system with only one HS-4 is the same at around 0.47 over time. This means, the multiplication of HS-4 does not affect the value of the thermoelectric COP. Thus, this COP is relatively higher than the previous studies, namely from 0.011 to 0.34 [1-9].

4.4 Analysis of the Effect of Expansion and Multiplication of HS on Electric Power

To observe the effect of HS expansion on electric power consumption, measurements were made of the total power consumption for 190 minutes, for both the

use of one HS-4 and four HS-4s. The results were 0.31 kWh and 1.23 kWh, respectively. Furthermore, the amount of electric power can be calculated in the following way.

For one HS-4, the electrical energy of 0.31 kWh can be converted to electric power as follows:

P = (0.31 x 1000 Watt hours)/(3.16 hours) = 98.1 Watts.

Meanwhile, for four HS-4s, the electrical energy of 1.23 kWh can be converted into

P = (1.23 x 1000 Watt hours)/3.16 hours = 389.24 Watts

Then, with the same cooling capacity, the use of four HS-4 requires four times the power consumption of one HS-4.

5 CONCLUSION

Based on the data and performance analysis, it can be concluded that for both expanding the heatsink (HS-4) and multiplication of the HS-4, the lowest cold junction temperature, lowest cabin temperature, COP , power consumption are -1.36ºC, 6.23ºC, 0.47 , 98.1 Watts and -3.64ºC, 1.93, 0.47, 389.24 Watts, respectively . This means that the designed thermoelectric refrigeration system can reach a cabin temperature close to 0 ^{0}C so that it can be used to cool soft drinks and preserves fruits in limited quantities. In addition, the obtained results are better than previous studies.

NOMENCLATURES

Symbols

COP	Coefficient of Performance
Qc	The amount of absorbed heat (W)
α	Seebeck coefisien (V/K) I Electrical current (A)
Tc	Cold junction temperature (K)
ΔT	Temperature difference (K)
θ	Thermal resistance (K/W) R Electrical resistance (Ω).
V	Voltage on the thermoelectric (Volt)
P	Input power on the thermoelectric (W)
Qr	The released heat into the environment,
h	Convective coefficient,
A	Area of heatsink,
T_{cabin}	Cabin temperature
T_{cold-J}	Cold junction temperature
T_{set}	Setpoint temperature
$T_{heatsink}$	Heatsink temperature
$T_{product}$	Product temperature
HS	Heat Sink
LCD	Liquid Cristal Display

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