Development and investigation of thermoelectric cooling performance based on space scales

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Abstract. The refrigerator is the key component to keep the medicine and biological sample in the hospital. However, the refrigerator that commonly used in the refrigerator will bring a negative effect to the environment. Other than that, the domestic refrigerator also has the problem of larger size and heavier weight since to the compact system like condenser, compressor, evaporator and expansion valve are assemble and use in the refrigerator. This study focused on the development of temperature control of the portable thermoelectric refrigerator for medical purpose. Thermoelectric cooling is using the thermoelectric refrigeration method through a thermoelectric module. This project is to analyze the space scales of the system which can perform a desired temperature control for the thermoelectric refrigeration. A commercial portable thermoelectric cooling is modified, which is able to achieve the temperature within the range of 8°C to 15°C by controlling the input current. Modification of this refrigerator is done by changing the original circuit of the refrigerator into a new circuit. The resistance temperature detector is used to replace the original thermostat that used to measure the inner temperature of the refrigerator. The input current is controlled by MOSFETs by using the pulse width modulation method. The temperature response of normal and small scale of thermoelectric cooling is 13.88°C and 10.91°C when input current 3A injected.

1. Introduction

In the hospital, the medicine entities such as blood sample, medicine and vaccine are the elements that very sensitive to the temperature. Most of the medical product will occur the changes in the chemical, physical and microbiological if the temperature keeps the product is exceed the desired temperature of that medical product [1]. For example, the blood bag shall maintain in +2°C to +10°C during transport and +2°C to +6°C for storage, vaccine maintain in -3°C to +8°C and the injection antibiotic should maintain in +8°C to +15°C [2–4]. The refrigerator used to store the medical product in the hospital usually is the domestic refrigerator which heavy and larger. Hospitals often use domestic vapour refrigerators to store biomedical specimens. The vapor refrigerator uses Chlorofluorocarbon (CFCs) and Hydro Chlorofluoro (HCFCs) as a refrigerant that will cause the negative effect to the environment like derogation of ozone layer [5]. This kind of refrigerator is considering as not eco-friendly. The refrigerator only can operate by using AC power source and this also means that the refrigerator is not suitable to use in a rural area that may not have any AC power supply. Therefore, the thermoelectric refrigerator is the alternative choice for storing the sensitive material since it can be operated on either AC power source or DC power source. Since the refrigerator can be operated using a DC power source, it can be used to transport the medical product to other places out of the hospital. The thermoelectric module inside the refrigerator able to
cool down the refrigerator because the temperature differential (hot and cold) will occur between both sides of the thermoelectric modules when the DC current passes it and this is known as thermoelectric effect [6]. Since the refrigerator can be operated using a DC power source, it can be used to transport the medical product.

2. Methodology

This study is conducted on a portable thermoelectric refrigerator. The desired temperature range of 8°C to 15°C will be able to achieve by the refrigerator for biomedical purposes like medical storage. There are few components used to develop this refrigerator.

2.1 Modification of Thermoelectric Refrigerator

The refrigerator is in a 12 liters portable refrigerator and the dimension is 41cm x 28cm x 29cm. The mass of this refrigerator is 5.3kg as shown in Figure 1. This refrigerator has a transformer and a full bridge rectifier to change the AC power source, 240VAC and 50Hz to a 24VDC power source to operate the thermoelectric devices. Other than that, this thermoelectric refrigerator can also operate by using the 24VDC power source such battery. Two thermoelectric devices are used in the refrigerator in order to improve the performance of the refrigerator. The desired temperature of the system is from 8°C to 15°C. Polystyrene is used to reduce the internal space of the refrigerator in order to reduce the time of cooling and increase the performance of the refrigerator.

![Portable thermoelectric refrigerator](image)

**Figure 1.** Portable thermoelectric refrigerator

The thermoelectric refrigerator system is modified from the original refrigerator system. In order to achieve the desired temperature range which is +8°C to +15°C, the input current must be controlled appropriately. In order to control the input, MOSFETs have been used in the modified circuit to replace the relay as shown in Figure 2. The MOSFETs will be triggered by the Arduino Mega microcontroller using the pulse width modulation (PWM) method. In this section, the conventional circuit will be modified by using a resistance temperature detector (RTD) to replace the thermostat.
2.2 Time Response of Thermoelectric Refrigerator

The step response is an output of the system produced by a unit step input. It is a common analysis tool used to determine system performance. The time response experiment is conducted in two different scales of the thermoelectric chamber. The time response can be described by the following quantities which are steady state and settling time. The time response experiment is conducted based on open-loop. For this experiment, step rest introduced to the refrigerator system is the form of open-loop identification.

The program of the project is in the form of a block diagram. A duty cycle control of PWM and temperature display program during the testing of the performance modified refrigerator, the temperature of the RTD sensor measured will show in the display block diagram and the PWM of the Arduino board can be also controlled through adjusting the value of the slider gain in Figure 3. In order to determine which input current can optimize the performance of the modified refrigerator, there are 4 different input currents tested which are 2.5A, 2.6A, 2.8A and 3A. The steady state temperature and the settling time for each input current are measured and recorded and the comparison is made between the results. The ambient temperature during the experiment is within 28°C to 29°C and the inner space of the refrigerator is not reduce using the polystyrene. The duration of each experiment is 140 minutes and the data sample will be measured and recorded every 2 minutes. After the best input current to operate the refrigerator is decide, the internal space of the refrigerator is reduced. The internal space of the refrigerator is reduced by using the polystyrene to fill up space. The volume of the original refrigerator is 410 mm x 280 mm x 29 mm and the volume after fill in the polystyrene is 100 mm x 103 mm x 1230 mm.
Figure 3. A simulink block diagram of the open-loop step response.

3 Result and Discussion

Experiment 1 is to decide the best input current for the modified refrigerator and the result is recorded in Table 1. From the Table 1, the input current able to achieve the desired temperature for the modified refrigerator is 5.2A-6.0A.

Table 1. Steady state temperature response of normal scale thermoelectric refrigerator due to the input current.

| Input Current (A) | Temperature (°C) | Settling time (Min) |
|------------------|------------------|---------------------|
| 5.0              | 17.22            | 98                  |
| 5.2              | 15.19            | 94                  |
| 5.6              | 14.42            | 86                  |
| 6.0              | 13.88            | 76                  |

When the input current is 6.0A, the temperature measured and recorded is 13.88 and this is the lowest temperature obtained in experiment 1. The settling time when 6.0A input current used is 76 minutes. The refrigerator system has the worst response when 5.0A input current is injected as shown in Figure 4. The temperature of the refrigerator is higher compared to other value of input current and the settling time for the system is longer.
Figure 4. Temperature response of normal scale refrigerator due to the input current.

Next experiment is to decide whether the internal space of the refrigerator will affect the response of the system. Two different internal space refrigerators are tested using maximum input current 6A. Figure 5 shows the graphs of temperature vs. time of two different internal spaces.

Figure 5. Temperature response of normal scale refrigerator due to input current.

The smaller internal space has faster response and the temperature is lower than the normal internal space. From the Table 2, the smaller internal space refrigerator has the faster settling time and the lowest temperature of this system is 10.91°C.
Table 2. Comparison steady state temperature response of thermoelectric refrigerator at 6 A.

| Space scale | Temperature (°C) | Settling time (minutes) |
|-------------|------------------|------------------------|
| Normal      | 13.88            | 76                     |
| Small       | 10.91            | 66                     |

From the first experiment, the current input 5.6A to 6A able to operate for biomedical storage application. Other than that, the internal spaces of the refrigerator also affect the response of the refrigerator system. When the internal space is smaller, the refrigerator is able to obtain a lower temperature and the settling time of the refrigerator is much faster.

4 Conclusions

A thermoelectric refrigerator system is modified to design and develop a new control system to improve the performance of the refrigerator. The modified refrigerator system can vary the input current of the refrigerator in order achieve an inner temperature of the refrigerator in the desired range. This refrigerator is able to operate using the AC power source from a wall socket or the DC power source from the battery.

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5 References

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