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Experimental study for comparing heating and cooling performance of thermoelectric peltier

Termoelektrik peltier'in ısıtma ve soğutma performansının karşılaştırılması için deneysel çalışma

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Experimental Study for Comparing Heating and Cooling Performance of Thermoelectric Peltier

Highlights

- *Thermoelectric performance is obtained in heating and cooling mode.*
- *COP value in both modes is compared.*
- *Possibility to use Thermoelectric device for heating and cooling is discussed.*
- *Thermoelectric Peltier device and vapor compression refrigerators are discussed.*

Graphical Abstract

Graphical Abstract of the study is provided to illustrate working principles with schematic view of the thermoelectric system.

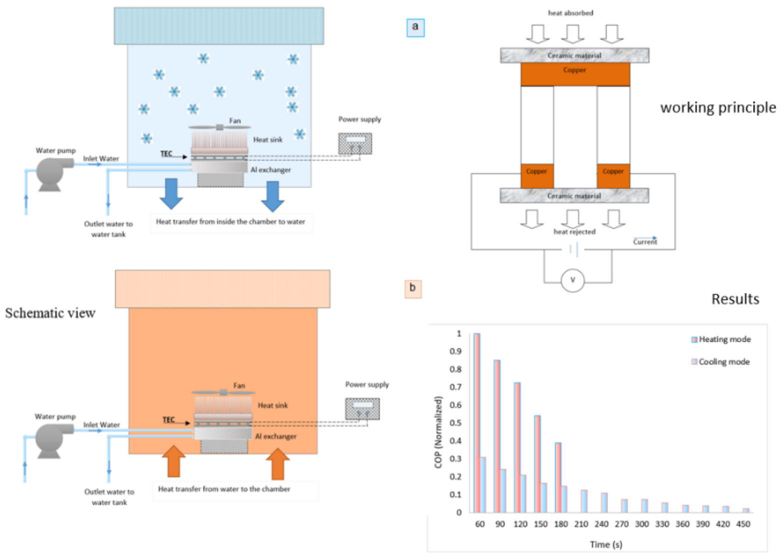

Figure. Graphical Abstract

Aim

The main aim of this study is to compare heating and cooling performance of Thermoelectric Peltier

Design & Methodology

Test box is manufactured using foam plates and Peltier device and required elements are placed as shown in schematic view.

Originality

Cooling performance of Thermoelectric device has been widely investigated in the literature. However, in this study, cooling and heating performance of the same device is compared.

Findings

It was revealed that, normalized COP of heating mode is 233% more than cooling mode at first 60 seconds.

Conclusion

Cooling mode results showed that, temperature of the refrigerator can be dropped to low levels below the freezing temperature of the water. It was shown that COP value of heating mode is remarkably higher than cooling mode.

Declaration of Ethical Standards

The author of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Experimental Study for Comparing Heating and Cooling Performance of Thermoelectric Peltier

Araştırma Makalesi / Research Article

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ABSTRACT

On a global scale it is considered that, a notable part of the overall electrical energy is consumed in refrigeration and air conditioning sectors. Refrigeration sector is also known as an important and critical industry in the field of food and pharmacy sectors. In general refrigeration and also freezing applications are based on the extracting thermal energy from the freezing or cooling medium to keep the temperature at the specified standard levels suitable for storage foods or medicines.

Vapor compression refrigeration systems are mostly employed for cooling, heating and air conditioning purposes, but comparative investigations focused on thermoelectric devices and their efficiency with well-known vapor compression refrigeration systems are less regarded in the literature.

In this study, Peltier thermoelectric performance was obtained in two different ways and the results were compared. First, the COP value was obtained when cooling was carried out in an insulated box and then in different mode, the heating of the box was carried out. It was observed a big difference between COP values of heating and cooling modes. According to the achieved experimental results of this study, the COP or coefficient of performance value in the heating mode is approximately 200% greater than that of cooling mode.

Keywords: COP, energy efficiency, two stage thermoelectric refrigerator.

1. INTRODUCTION

Preserving medicine, fresh foods and vegetables in suitable and clean conditions is a serious issue for human health. Generally, vapor compression cycles are used for cooling and heating applications in homes and industry. However, thermoelectric devices can be also employed to provide cooled and heated medium, which is an important alternative for the vapor compression. In the literature thermoelectric systems have been investigated by many investigators with regard to energy efficiency categories as well as optimum working conditions. The optimum input electrical currents were distinguished in a various heat loads performed by Chang et al. [1].

Thermoelectric materials, modeling approaches and applications were reviewed in another study and Thermoelectric cooling applications (electronic cooling systems, domestic refrigeration, and air conditioning of automobile) were analyzed [2]. Vapor compression heat pump systems and also refrigerator systems were investigated in detail to enhance their efficiency employing thermoelectric generation by using compressor heat losses [3]. Performance of vapor compression heat pump were analyzed using different types of lubricating oil for a system operated by a reciprocating compressor [4]. Thermal equations and formula were developed to figure out analytical solutions for the performance and device temperature effect at the both side by Zhang [5]. In other study [6], Yin et al. (2017) examined the effect of adding TE generator on the efficiency of four different PV cells, including monocrystalline silicon, amorphous silicon, polycrystalline silicon and polymer photovoltaic cell. It was found that with increasing the thermal resistance of TE the performance of the system can be considerably enhanced using silicon or polymer cell. In addition, some researchers used thermoelectric for cooling applications. Optimized heat transfer, is considered as one of the most important problems in the cooling-heating systems especially in the industrial process, which is a significant subject for many research presented in the literature [7-8]. Mini size water cooled TE refrigerator was investigated and coefficient of performance of the system was calculated in different voltages and flow rates over the test time by Gokcek et al. [9]. A prototype TE for domestic-refrigerator was examined and the system efficiency was evaluated and calculated in terms of the COP and cooling rate [10]. Two stage TE coolers were utilized to enhance the cooling capacity value and coefficient of performance of thermoelectric and the applied electrical current was optimized in other study by Cheng et al. [11]. Caglar [12] manufactured and studied optimum working conditions for a mini TE refrigerator utilizing Peltier device. Peltier-fans combination were used on both sides of refrigerator box. Their results revealed that optimum ambient temperature is about 293 K. Also, coefficient of performance decreases from 0.351 to 0.011 when the temperature of the cooled side reduces from 293 K to 254.8 K. Tan et al. [13] in other research, theoretically investigated a thermoelectric cooling scheme to obtain the optimal operating conditions using thermodynamic second law. They research team

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Table 1. TE device, water pump and heatsink characteristics

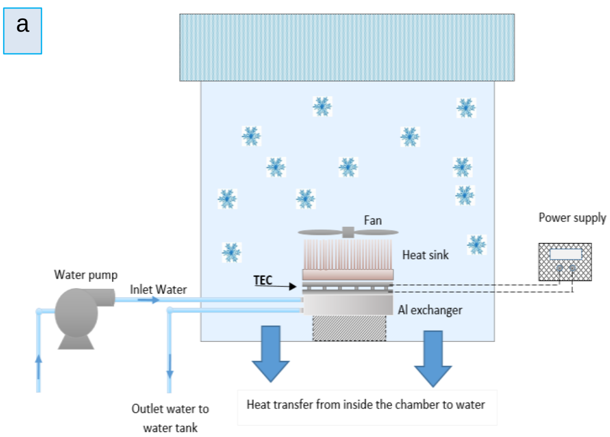
Peltier thermoelectric characteristics						
Product type	Working current (A)	I_{max} (A)		Working voltage (V)	Q_{max} (W)	Size (mm)
TEC1-12715	< 3	15		12	231	40 × 40 × 4
Water pump characteristics						
product type	Working voltage (V)	Working current (mA)	Flow rate (kg/s)	Highest pressure (mmHg)	Hose connection size (mm)	Dimensions (mm)
SKU 50200	12	< 320	0.02	360	6.5	D27 × 75
Heat sink characteristics						
product type	Material	Power (W)	Number of teeth	Bottom plate thickness (mm)	Tooth thickness (mm)	Dimensions (mm)
FLE-CO0208	Aluminum	5.1	27	4.6	1.0	200 × 70 ×35

surveyed effects of different factors including electrical current, thermal conductivity of the material and cooling temperature on performance of installed system. The achieved outcomes illustrated that cooling temperature is the most important factor affects TE cooling performance. Modified pulse operation of TE for building cooling numerically analyzed by Manikandan et al. [14]. TE cooling system was investigated by applying various cooling load, variable pulse width, variable pulse current ratio, and dissimilar pulse shapes. The findings figured out that modified pulse operation could increase the cooling rate and COP value by 23.3% and 2.12% in comparison with normal mode. TE refrigerator powered by solar PV cells and electric storage system was studied by Enescu et al. [15]. Dimri et al. [16] provided an estimation model for semitransparent PVT system which was equipped with thermoelectric device. Their achieved results illustrated that adding TE apparatus to the semitransparent photovoltaic scheme increased the electrical performance by 7.266%. Wang et al. [17] utilized small type TE for microprocessors chip cooling. Both experimental and numerical results were used to indicate the effects of using this type of cooling system on microprocessors performance. The obtained results revealed the importance of thermal contact resistance. Higher thermal contact resistance needs a larger mini-contact to achieve optimum system performance. The main objectives of this work are experimentally analysis on Peltier thermoelectric heating and cooling performance, COP values in different working conditions and task result over the test time.

2. MATERIAL and METHOD

In this study, two refrigerator boxes were made at same dimensions by using foam insulation materials and two different heating and cooling modes have been tested as shown in Fig. 1.

In Direct Current (DC) electric charging, Peltier systems can easily cool and heat the desired environment by changing the plus and minus electrical inputs. Cooling and heating modes have been demonstrated in Fig1-a and Fig1-b respectively. The capacity of fabricated boxes is 15×15×15 cm and the temperature changes were measured and recorded using T type thermocouples over test time and average temperature of the boxes were obtained and used in calculations. Voltage/Ampere meter device was utilized to calculate electrical power consumption of the TE Peltier device, fan and mini water pump. All materials and elements in the heating and cooling modes are the same and experiments were carried out without making any changes in Peltier device and required connections. A 12V, TEC1-12715 Peltier device was employed for cooling and heating inside boxes (test chamber). For every experiments water supply flow rate is fixed at 1.17 kg/s provided by a SKU 50200 -12 V mini water pump. Peltier thermoelectric, water pump and heatsink features have been provided in Table 1 and also a picture of experimental setup and schematic of thermoelectric are illustrated in Fig. 2.



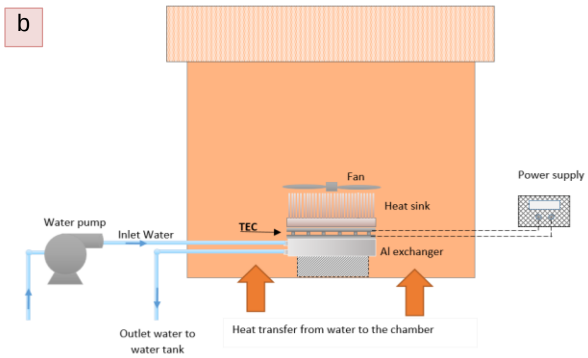


Fig. 1. Schematic view of cooling (a) and heating (b) operation modes

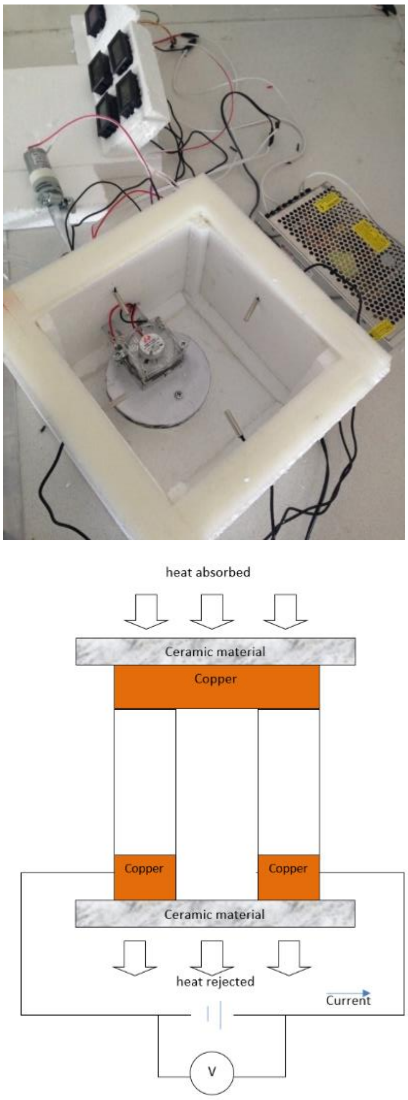


Fig. 2. A picture of experimental setup and schematic view of thermoelectric

3. EFFICIENCY ANALYSIS

Basically, in previous studies carried out in the field of thermoelectric Peltier, calculations are performed by two dissimilar ways. Analysis is launched with the prediction of the TE heating power as well as cooling power in the first way for calculation. Assuming constant electrical properties and thermal characteristics of used thermoelectric Peltier, absorbed cooling value at the cold side (Qc) and heating amount at hot side (Qh) are stated as [1],

$$Q_c = \alpha\, T_c I - \frac{1}{2}(I^2 R) - K(T_h - T_c) \quad (1)$$

$$Q_h = \alpha\, T_h I - \frac{1}{2}(I^2 R) - K(T_h - T_c) \quad (2)$$

Coefficient of performance or COP of the TE material can be written as follow,

$$(COP)_{c,max} = \frac{T_c}{T_h - T_c}\, \frac{\sqrt{1+ZT_m} - \frac{T_h}{T_c}}{\sqrt{1+ZT_m}+1} \quad (3)$$

here ZT_m is the TE material figure-of-merit value which can be obtained by average cold and hot side temperature T_m.

In other method (second way calculation) which has been used in this study, power consumption value of the TE, and also water pump and fan elements are taken into account and so the overall system COP can be expressed as,

$$COP_{Tot} = \frac{Q_c}{W_{pe} + W_{fa} + W_{Pu}} \quad (4)$$

It should be stated that, COP is basically thermodynamic value as a ratio of obtained thermal energy to consumed power. A literature review showed that in most studies thermodynamic calculation has been used and obtained results seem to be more logical using thermodynamic method. Furthermore, the absorbed heat value from the enclosed test box can be computed using equation (5).

$$Q_c = mC_\rho(T_2 - T_1) \quad (5)$$

here the first and last temperature of the box are T1 and T2 respectively. m is the value of trapped air mass existing inside the box. Having density of air and volume of the refrigerator box, the contained mass in the insulated box can be obtained from,

$$m = \rho v \quad (6)$$

electrical power consumed in the system is obtained from recorded voltage and current values as,

$$W = VI \times (t) \quad (7)$$

Heat transfer rate for water cooled side of the system can be stated by following equation,

$$Q = \dot{Q} \times t = (\dot{m} C_{\rho,water}(\Delta T)) \times t \quad (8)$$

4. RESULTS AND DISCUSSION

In the present study, performed tests have been conducted to analyze heating and cooling performance of a specified thermoelectric in two same-dimension boxes. The inside box temperature of the insulated boxes was register over performed tests and obtained average temperature from used thermocouples was computed. Temperature variation over test time is given in Fig. 3 for two heating and cooling modes. It should be noted that, cooling mode experiments were carried out during 480 seconds, but 210 seconds for heating mode. The reason for this application is that, in the heating mode temperature increasing of the medium can cause the Peltier device to burn up and destroy. In other words, in the case of heating mode, initial temperature was decreased to low levels lower than ambient temperature to handle experiments in large range at medium temperatures, because the operating temperature of the Peltier device is limited and can be damaged at high temperatures.

In the figure it is seen that, the temperature has dropped below 0°C in cooling mode and about 40°C in heating mode. It should be stated that, temperature of the box was decreased to 5°C in heating mode to obtain results in larger interval.

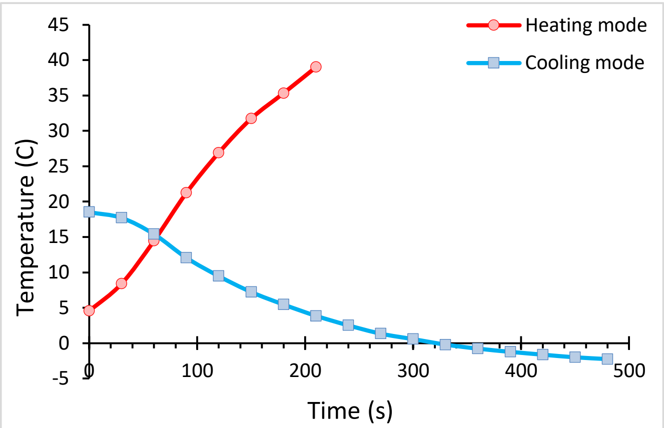


Fig. 3. Temperature variation with respect to test time in two modes

In Fig. 4, power consumption of two modes has been compared with respect to test time. Obtained results showed that, the value of consumed power in cooling mode is approximately 58% more than that of heating mode.

In Fig. 5, extracted and imported thermal energy have been calculated using temperature variations inside boxes in cooling and heating modes. Decreasing trend was observed over test time in both modes. However, thermal energy values in heating mode is remarkably higher than cooling mode.

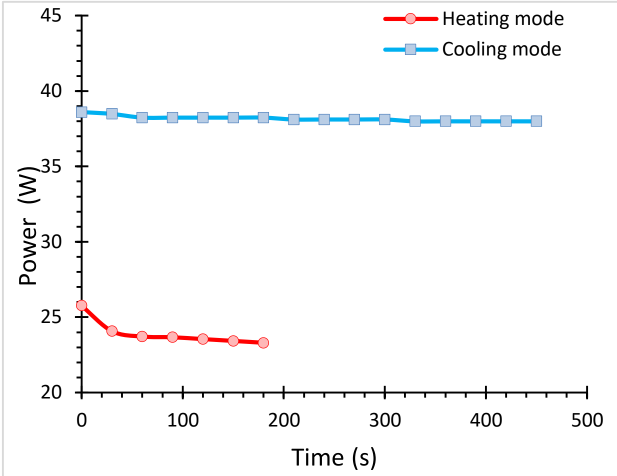


Fig. 4. Power variation with respect to test time in two modes

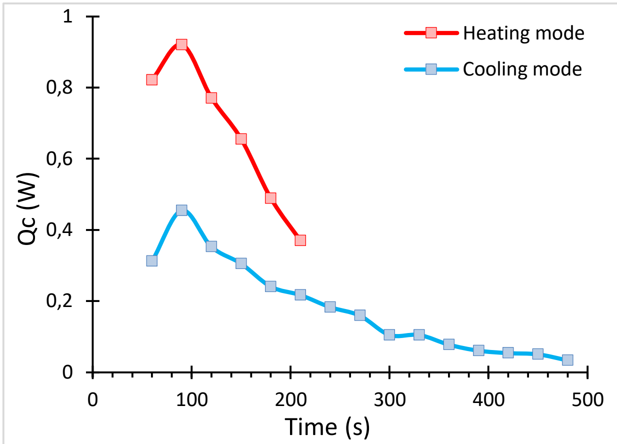


Fig. 5. Extracted and imported thermal energy in cooling and heating modes

For better comparing normalized COP values were calculated as shown in Fig. 6. Obtained results clearly represents that, COP of heating mode is remarkably higher than that of cooling mode. In general, calculated COP values are low and smaller than 1. Considering a large number of studies, however, it can be observed that this value is even smaller than 0.1 and COP of vapor compression systems seems to be higher than that of TE by considering working condition, time factor and etc. Obtained results shows that, in both cases COP values decreased during test time and as a result performance of the system is gradually reduced.

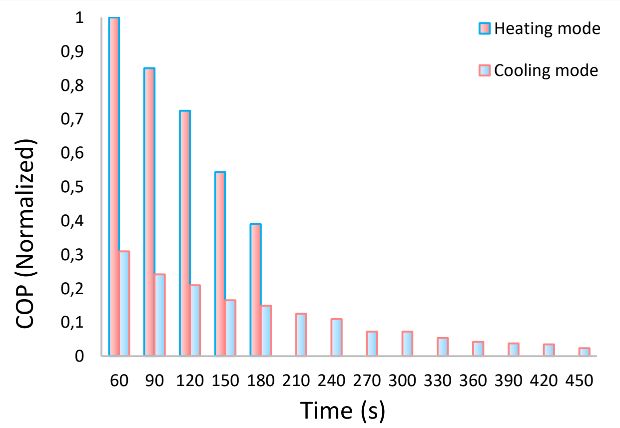


Fig. 6. Normalized COP value for heating and cooling modes

5. CONCLUSION

In this study, air to water Peltier thermoelectric performance has been experimentally investigated to evaluate COP values in different working conditions at heating and cooling modes over the test time.

Cooling mode results of air to water Peltier thermoelectric showed that, temperature of the refrigerator can be dropped to low levels below the freezing temperature of the water. It was revealed that, normalized COP values of heating mode is 233% more than that of cooling mode at first 60 seconds. However, power consumption of cooling mode was more than heating mode.

COP and thermal energy calculations showed that, these values decrease over the time, which is an indication for limited medium that is a closed container.

Nomenclature	
COP	Coefficient of performance
C_p	Specific heat capacity (J kg^{-1} K^{-1})
I	Electric current (A)
K	Device thermal conductance (W K^{-1})
$\dot{m}$	Flow rate of mass (kg s^{-1})
m	Mass (kg)
$\dot{Q}$	Heat transfer rate (W)
Q	Heat transfer (J)
t	Time (s)
T	Temperature (°C)
v	Volume (m^3)
V	Voltage (V)
W	Power consumption (W)
TE	Thermoelectric
ρ	Density (kg m^{-3})
μ	Dynamic viscosity (kg m^{-1}s^{-1})
α	Seebeck coefficient (V K^{-1})
Subscripts	
c	Cold side
fa	Fan
h	Hot side
Pe	Peltier
Pu	Water pump

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