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Enhancing COP and Cooling Temperature for Peltier with Decreasing Power, and Chemical Composition Negative Effect by Optimizing Connection, Position Angle, and Voltages

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In Loving Memory of Late Professor Doctor ""Mohamed Refaat Hussein Mahran""

Abstract

The energy challenges and global warming resulted in maximizing the energy efficiency utilized to minimize consumption. Thermal cooling was less prevalent, it can be used to reduce carbon emissions and global warming. Thermoelectric cooling uses the Peltier effect to create a heat flux at the junction of two different types of materials. Peltier connection technology affects the cooling efficiency (parallel series). The location of the Peltier, usage periods, and chemical composition affect the cooling capacity, such as the different Peltier positions on a parallel or vertical, that was, the position between two Peltier units is at a 180-degree angle or a 90-degree. Different voltages, coefficient of performance (COP), and cooling temperature (Tc) were studied over time to improve Peltier efficiency. The result proved that the parallel connection is better than the series connection and the position angle of 90° for Peltier in the box. at the position angle of 90°, Voltage 10 V, the temperature of water decreases from 30.9 °C to 12.5 °C, (the best cooling value) and the Peltier average current is 4.59 A. While at 4 V, the average current through the Peltier element is 1.833A and the COP is 66.3%.

Keywords: COP, Cooling capacity, Power consumption, Thermoelectric module, Position Angle.

1 Introduction

The current global issues include the energy crisis and restrictions on the most effective use of renewable energy resources, affecting sustainable growth [1,2]. Energy demand is increasing. Due to their reduced environmental effect, several renewable energies have been developed to close this gap [3,4].

Zuhair R. Abdulghani used the well-known Taguchi method which provides an empirically based optimization process for a Peltier air cooler and presents an experimental approach to improving a Peltier air cooler. The research indicates that adding Peltier units leads to a higher coefficient of performance (COP) for the total specified input power [5].

Numerous studies on TE cooling have combined experimental and theoretical data. Typical shell and tube heat exchangers were modified to use a tubular TE device made of tilted multilayers of BST/Ni as the tubes to provide a more efficient heat exchanger, [6–8].

Astrain et al. A 15 m3 thermoelectric refrigerator was subjected to a computer analysis to ascertain the impact of the heat exchanger under investigation on the refrigerator's total consumption and efficiency. The results demonstrate that TEC efficiency can be significantly increased with efficient heat exchanger tuning, [9].

Chen et al. showcased an example of an irreversible thermoelectric refrigerator powered by an internal and external generator While the cooling load is lower and no longer proportionate to the total number of thermoelectric units, the COP is no longer constant and instead decreases monotonically as the total number of thermoelectric devices increases [10,11].

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Çağlar A. created a portable TE refrigerator. Using an orthogonal fractional factorial experiment design approach, the temperature and COP of the TE refrigerator are evaluated to determine the optimal operating parameters over 60-minute duration. The findings show that while the COP decreases from 0.351 to 0.011, the TE refrigerator's internal air temperature decreases from 293 K to 254.8 K, [12].

Carson et al. studied a laboratory experiment conducted to determine the impact of the orientation of the cold side heat sink on the rate of water collection. On the side of heat rejection, a single-finned heat sink-fan combination was employed. A heat sink with fifteen fins, a fanned plate with four fins, and uncoated and Polytetrafluoroethylene (PTFE) coated flat plates were utilized on the cold side, [13].

Lumin Shi et al. presented Three Peltier air coolers of different sizes (but in the same total input power range) that were studied from the point of view of efficiency and economic cost. The results show that despite the high capital and maintenance cost this means that although increasing the unit number enhances the total COP of the chiller (for a given input power) and reduces the cooling cost, a further increase in the unit number will ultimately increase the cooling cost of the chiller. The quantitative and qualitative results of this research can be useful for marketing purposes and future commercialization of a large-scale air cooling process using a Peltier unit, [14].

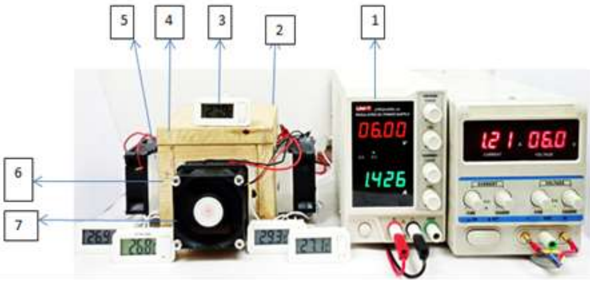
Improved the functioning and created a TE cooler for cooling electronics by applying a topology optimization approach. Based on evaluations of voltage, current, and temperature, [15,16]. A parabolic method was developed to calculate the peak efficiency of TE modules based on temperature, current, and voltage data, [17–19]. used a simple evaporative cooling system, which increased COP by 20.9%, [20]. Studied heat dissipation strategies for eliminating waste heat from a TE device's cold side A TE freshwater generator was created, [21]. For use by dwellers of humid and coastal environments with relative humidity values greater than 60%. They require a lot of electricity, employ liquid refrigerants that have significant environmental effects, and are difficult to create as portable and lightweight outdoor equipment [22,23].

Through the study, it was found that with the continuous use of the Peltier element, damage to the Peltier element occurs as a result of changes in the chemical properties of the Peltier element. To improve the efficiency of the Peltier and rationalize energy consumption, different positions of the Peltier element were studied at an angle of 90 and at an angle of 180 to find out the most appropriate position. Connecting the Peltier in parallel and series was studied to avoid changes in the chemical properties.

2 Materials and method

2.1 Cooling system description

The photographic picture of the experimental configuration is shown in Figure 1. the proposed system consists of a refrigerator box containing four thermoelectric units (TU). The thermoelectric unit consists of three parts: Peltier, a heat sink, and a fan. The main part is a Peltier element (TEC1-12706). It is a semiconductor with N-P junctions with copper conductors. Dimensions: (4×4×4) cm. Voltage 14.4V DC. Current 6A, Temperature range: 30:70℃. The chemical component of Peltier is aluminum oxide. Although Al_2O_3 is an electrical insulator, it has a high thermal conductivity (30 Wm^{-1} K^{-1}). Aluminum oxide is insoluble in water. A heat sink made of aluminum with dimensions 6.8×6.6×3.6 cm, and an aplastic fan with dimensions 6.5×6.5×2.5 cm. The refrigerator box is powered by a power supply with variable voltage.



1- Power supply 2- S.S. box 3- Sensor 4- wood box
5- Heat sink 6- Peltier element 7- Fan

Fig. 1. Photographic view of experimental setup.

Through laboratory experiments, it has been shown that continuous use of the Peltier element without stopping leads to a change in the chemical composition of the Peltier element, which leads to its destruction. Therefore, a fan and heat sink must be installed to remove heat from the hot end of the Peltier. RB Refrigerator box is made up of two boxes: an exterior box made of wood and an inside box made of stainless steel, with thermal insulation (Foam) inserted between them to prevent cooling loss.

To obtain lower temperatures on the cold side of a Peltier element, the hot side must be cooled. As a result, a fan is often used on the hot side of the Peltier element. A digital sensor was used to measure the temperature of the Peltier device, the water inside the insulated box (cooling load), and the heat sink.

This work consists of two parts the first part studied the effect of connection in cooling temperature. Connected Peltier in (series – parallel) connection by using (2, 3, and 4) Peltier, two Peltier at different voltage (4, 6, and 8) V while three and four only at 4 volts. Second part studied the effect of position of the Peltier vertically at a 90º degree and straight line at an angle of 180º. Figure 2 represent the schematically diagram of experimental setup. It contains the refrigerator box and control unit to control the temperature inside the box by measuring the temperature of the water inside the box.

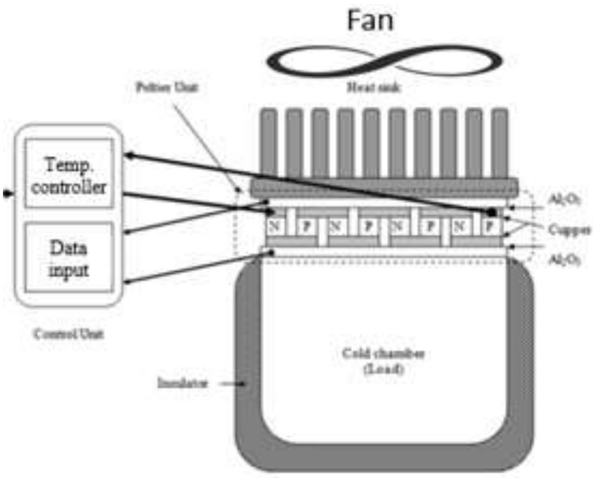


Fig. 2. schematical diagram of experimental setup.

2.2 Thermoelectric Cooling

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. Figure 3 shows a picture of Peltier element.

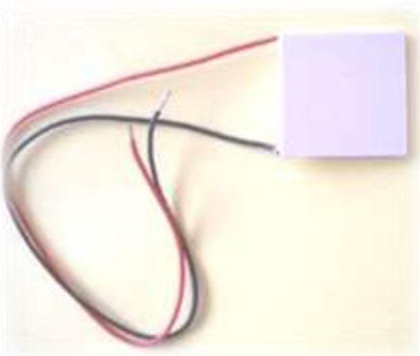


Fig. 3. Picture of Peltier module.

A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump that transfers heat from one side of the device to the other side against the temperature gradient (from cold to hot), with the consumption of electrical energy. Such an instrument is also called a Peltier device, Peltier heat pump, solid-state refrigerator, or thermoelectric cooler (TEC). The Peltier device is a heat pump: when direct current runs through it, heat is moved from one side to the other. The main advantages of a Peltier cooler are its lack of moving parts or circulating liquid, and its small size and flexible shape.

2.3 Method

Many experiments are carried out by using variable voltage (4-6-8) V, No. of Peltier (2-3-4) Peltier to improve the coefficient of performance (COP) and reduce the power consumption. at the start of experiments, put 250 grams of water in the refrigerator box and then record its temperature, adjusting the Voltage at specific values (4, 6, and 8) V, and record ambient temperature and the current of the Peltier element. The temperature of the water inside the box, the hot side of the Peltier, and the cooling temperature are recorded every five minutes. The duration of an experiment is an hour to a quarter. Then calculate The COP of the refrigerator system.

The ratio of heat produced by the Peltier unit to the energy supplied represents the COP. The equations used to get the COP of the refrigerator system are the following:

$$W = V \times I \times t \quad (1)$$

$$Q_{cooling} = mC_p\Delta T \quad (2)$$

$$COP = \frac{Q}{w} \quad (3)$$

Where W is the amount of energy required to working power the Peltier element, m is the mass of water, Cp specific heat of water ΔT the temperature difference between the initial temperature and cooling temperature, and Q is cooling capacity.

3 Results And Discussion

3.1 Effect of different connection series or parallel on COP at different Voltage and No. of Peltier.

Table 1 represents the results of the experiments are classified as the effect of variable Voltage 4, 6, and 8 V by using No. of Peltier elements 2, 3, and 4 on the cooling temperature and the COP, at different connections series or parallel, these variables have different impacts on the COP. The voltages for the Peltier and fan were studied, as well as the starting temperature and calculated COP values. Where V is the total voltage of the Peltier and fan, I represent the average current, and T represents the temperature difference. The best COP was 66.3%, which was the highest in the experimental study by using two Peltier units at 4 volts with parallel connection.

Table 1 The COP at different Voltage, No. of Peltier, and connection series or parallel.

Experimental No.	Parameters				Results		
	Volt (V)	No. of Peltier	Connection Type	Time (min)	Current (A)	ΔT (ºC)	COP (%)
1	4	2	parallel	45	1.833	12.5	66.30%
2	4	2	series	45	0.89	9.2	50.25%
3	6	2	parallel	45	2.5	13.7	35.52%
4	6	2	series	45	1.38	12.6	29.59%
5	8	2	parallel	45	3.815	16.2	20.64%
6	8	2	series	45	1.8	14	18.90%
7	4	3	parallel	45	2.66	15.7	57.38%
8	4	3	series	45	0.864	11.2	42.01%
9	4	4	parallel	45	3.538	18.2	50.01%
10	4	4	series	45	0.888	16	43.79%

Table 2 The COP at different Voltage, and different position 180 or 90º.

Experimental No.	Parameters				Results		
	Volt (V)	No. of Peltier	Angle	Time (min)	Current (A)	ΔT (ºC)	COP (%)
1	4	2	180°	45	1.883	11.3	58.34%
2	6	2	180°	45	2.518	13.2	33.98%
3	8	2	180°	45	3.815	15.6	19.9%
4	10	2	180°	45	4.596	18	15.2%
5	12	2	180°	45	5.548	18.1	10.6%
6	14	2	180°	45	6.478	17	7.29%
7	4	2	90°	45	1.833	12.5	66.3%
8	6	2	90°	45	2.5	13.7	35.52%
9	8	2	90°	45	3.8	16.2	20.64%
10	10	2	90°	45	4.573	18.4	15.65%
11	12	2	90°	45	5.718	18.2	10.32%
12	14	2	90°	45	6.294	17.9	7.90%

3.2 Effect of different position 180 or 90º on COP at different Voltage.

Table 2 displayed the results of laboratory experiments conducted under conditions at an ambient temperature of 30.9 °C, at different voltages, and using two Peltier units at a specified time of 45 minutes. With two different angles 180 or 90º. Since COP is the most significant comparative metric for cooling systems, it is applied as a performance benchmark to enhance quality. The operational factors that significantly affect the system's COP are the number of Peltier elements, voltage differential, and using parallel connections. The best COP was 66.3%, which was the highest in the experimental study by using two Peltier units at 4 volts, 1.833 A, with parallel connection and an angle position of 90º.

3.3 Effect of different connection on cooling Temperature with time and different voltages.

Figure 4 depicts the variation in cooling temperature with time, The graphic shows two, three, and four Peltier units in different connections series or parallel at time 45 min and different voltages 4, 6, and 8 V. The best cooling was 12.7 ℃ when decreased from room temperature 30.9 ℃ at 4 volts by using four Peltier units at parallel connection. The highest cooling temperature was 21.7 ℃ at 4 volts by using two Peltier at the series connection. It is also clear from the figure that the parallel connection is better than the series connection.

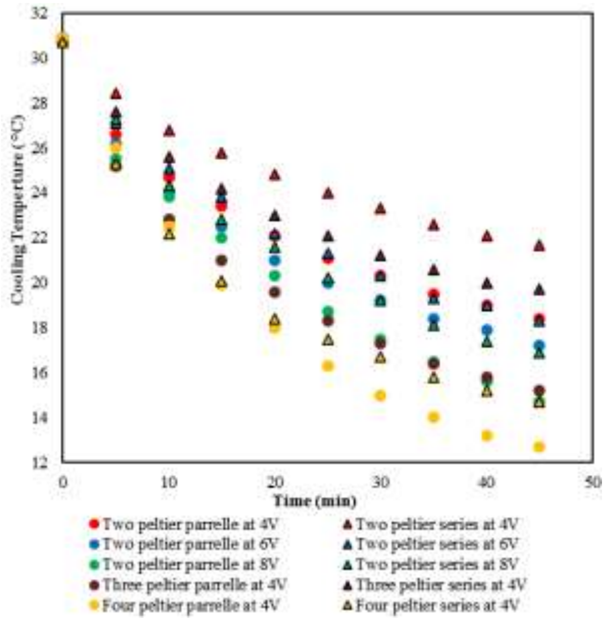


Fig. 4. Effect of different connection on cooling Temperature with time and different voltages.

3.4 Effect of different connection on power consumption with time and different voltages.

Figure 5 illustrates the variation of power consumption with time at different connections, The figure displays two, three, and four Peltier units are connected in different ways series or parallel at different voltages 4,6, and 8 V. The two Peltier using the series connection at 4 Volt had the lowest energy consumption, and the highest energy consumption was in the parallel connection by using two Peltier at 8 Volt.

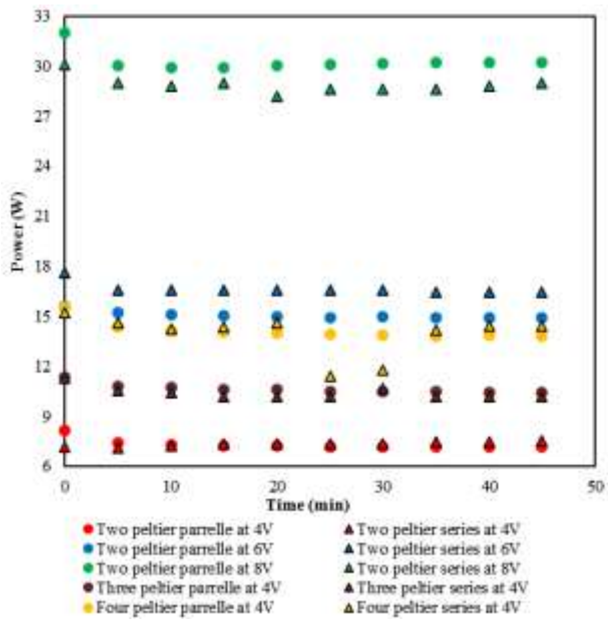


Fig. 5. Effect of different connection on power consumption with time and different voltages.

3.5 Effect of Peltier angle 180 or 90º on the cooling temperature and power consumption with time and different voltages.

Figure 6 displays the variation of temperature and power consumption by using two Peltier elements with a position angle of 90° at variable Voltage 4, 6, 8, 10, 12, and 14V. It is noticed that, at Voltage 10 V, the temperature of water decreases from 30.9 °C to 12.5 °C, (the best cooling value) and the Peltier average current is 4.59 A. While at 4 V, the average current through the Peltier element is 1.833A and the COP is 66.3%. When the input Voltage is increased, the current increases, but COP decreases. Also, the power reached 90 W at 14 V.

Figure 7 shows the temperature and power consumption when two Peltier elements with a position angle of 180º are used at different voltages 4, 6, 8, 10, 12, and 14V. At Voltage 10 V, the temperature of the water lowers from 30.9 °C to 10 °C with a temperature difference of 20.9 °C (the maximum cooling value) during the cooling time, and the average current of the Peltier element is 4.59 A. The best COP was 58.3%. at average current through the Peltier element is 1.833A at 4 V. When the input voltage is raised, the current rises, but the COP falls. Also, the power reached 87 W at 14 V.

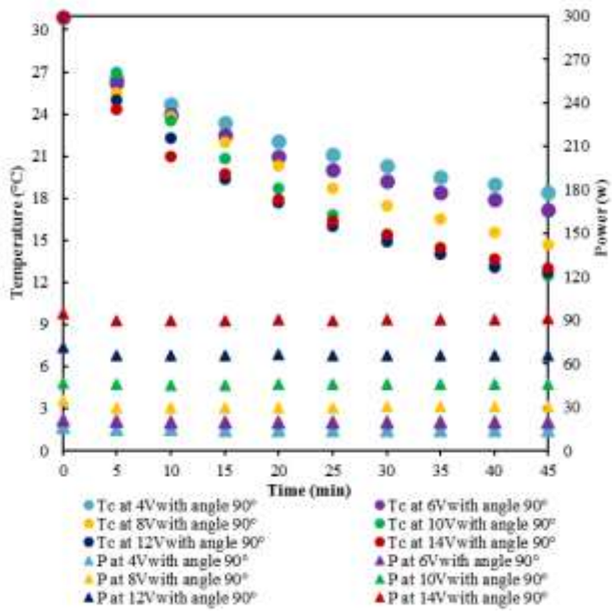


Fig. 6. Effect of Peltier angle 90º on the cooling temperature and power consumption with time and different voltages.

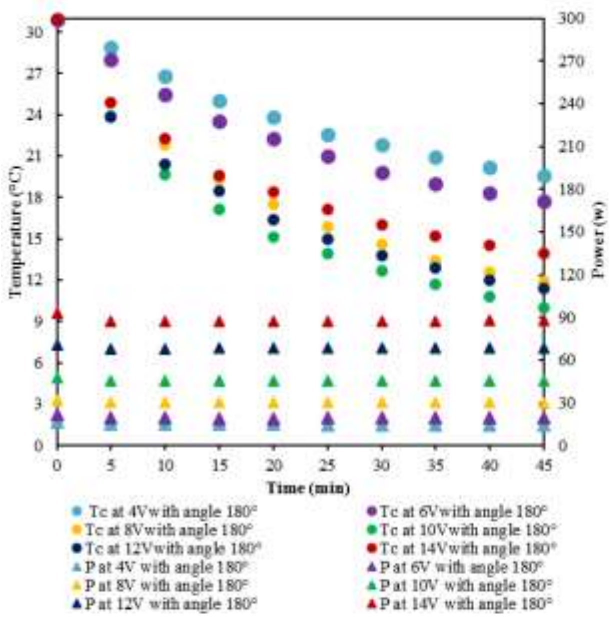


Fig. 7. Effect of Peltier angle 180° on the cooling temperature and power consumption with time and different voltages.

4 Conclusions

The conclusion is also clear that the parallel connection is better than the series connection and the position angle of 90° for Peltier in the box and this explains that:

- At the position angle of 90°, Voltage 10 V, the temperature of water decreases from 30.9 °C to 12.5 °C, (the best cooling value) and the Peltier average current is 4.59 A. While at 4 V, the average current through the Peltier element is 1.833A and the COP is 66.3%.
- At the position angle of 180°, Voltage 10 V, the temperature of the water lowers from 30.9 °C to 10 °C with a temperature difference of 20.9 °C (the maximum cooling value) during the cooling time, and the average current of the Peltier element is 4.59 A. The best COP was 58.3%. at average current through the Peltier element is 1.833A at 4 V.

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Nomenclature

TEMs	Thermoelectric modules
TE	Thermoelectric
TU	Thermoelectric Unit
COP	Coefficient Of performance
Ti	Initial temperature, °C
Cp	Specific heat of water, J kg−1 K−1
I	Current, A
m	Mass of water, kg
$\dot{Q}$	Heat transfer rate, W
Tc	The temperature of Cold junction,
Th	The temperature of Hot junction, °C
t	Time, s
$\dot{W}$	Power consumption, W
T	Temperature, °C
V	Voltage, V
TU	Thermoelectric unit
S.S.	Stainless steel
ΔT	The different of temperature