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Design and Development of Eco-friendly Thermoelectric Cooler

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ABSTRACT: This research aims to develop a cooling system that will provide a cooling effect using a thermoelectric module without the use of moving mechanical parts such as the condenser, compressor and evaporator. Working fluids (Refrigerants) are not required in a thermoelectric cooling system to produce a refrigeration effect. This device can cool liquid without the use of refrigerants. This compact design is particularly valuable for Choro fluorocarbon (CFC) elimination and would replace conventional refrigeration systems. In comparison to traditional compressors, which contain hazardous gases that are harmful to the environment, thermoelectric cooling is eco-friendly, vibration-free, and noiseless in operation. In the present work, the thermoelectric cooling system was fabricated by thermoelectric module (TEC1 12715) based on heat load calculation and 120 W DC electrical power (Switched-mode power supply) was supplied to a thermoelectric cooling system. The thermoelectric cooling system is provided with the fan to insist the forced convection to remove the heat from the hot side of the module. The cold side temperature of the thermoelectric cooling system was measured on a time basis for every 10 minutes interval. The temperature of the water was decreasing continuously from 34.2°C to 19.9 in one hour. In this work, it is analyzed the maximum COP of the thermoelectric cooling system was 0.48 and the maximum refrigeration effect was 57.6 W.

Keywords: Thermoelectric module, water cooling, temperature, refrigeration effect, C.O.P.

INTRODUCTION

Thermoelectric systems are solid-state devices that use a heat exchanger to transfer heat directly into electricity or electric power into thermal power. They can be used as a heater or chiller. The thermoelectric phenomena, which involve interactions between heat and electricity passing through solid material, are the basis for this device. The Seebeck effect and the Peltier effect are two examples of these phenomena. The thermoelectric phenomenon (Seebeck effect) was discovered in 1821 by Thomas Johann Seebeck. Thermoelectric cooling is based on a phenomenon discovered by Jean Charles Peltier Athanasius in 1834. By just applying a low DC voltage to this module, one surface will turn cold and the other will become warm. By simply reversing the supplied DC voltage, the heat travels in the other direction, allowing this thermoelectric device to function as either a heating or cooling device. The Peltier effect can be employed to carry energy in the form of heat.

Refrigerators with traditional cooling systems employ a compressor and a working fluid to transfer heat. As the working fluid expands and contracts, changing phases from liquid to vapour and back, thermal energy is acquired and released. Semiconductor thermoelectric coolers (also known as Peltier coolers) have several advantages over traditional systems. They are durable, reliable, and silent because they are completely solid-state devices with no moving parts. They don't use chlorofluorocarbons, which deplete the ozone layer. They can be significantly smaller than compressor-based devices. Temperature regulation is precise with a thermoelectric cooler. However, when compared to a standard refrigerator, their efficiency is low.

In vapour compression refrigeration, CFC (Cloro Fluro Carbon) refrigerant was commonly used as a working fluid. Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) are two environmental pollution consequences (GWP). According to numerous studies, refrigerant is responsible for between 15% and 12% of global warming, causing the earth's temperature to rise. As a result, the global biosphere will be degraded by ozone depletion and rising global temperatures.

People like to utilize systems that are not only ecologically friendly but also easy to transport and use when looking for a cooling solution. As a result, the equipment should be able to function as a cooler or heat pump, but it will not work with a refrigerator that uses vapour compression refrigeration. The TEC module is designed to address these issues.

Food preservation and processing, storage applications, electronic cooling, military field, car cooling, pharmaceutical product storage, air-conditioning and refrigeration area are only a few of the applications for thermoelectric cooling systems.

Principle. A thermoelectric cooler (TEC) is an electrical component made up of P- and N-type semiconductors. The Peltier effect is used in thermoelectric cooling systems. The TEC module receives a DC at a voltage of 12V. A temperature difference is created on both sides of the TEC module as a result of this effect. At one point, heat is eliminated and cooling happens. Heat is dissipated and heating occurs at the opposite junction.

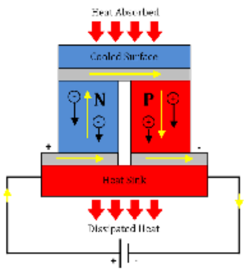

Fig. 1. Schematic diagram of Thermometric effect.

Thermoelectric systems are solid-state devices that use the Seebeck effect to operate. They are made up of a hot junction and a cold junction and when a temperature gradient exists between the hot and cold junctions, they convert heat energy into electrical energy. The Peltier effect allows solid-state thermoelectric devices to transform electrical energy into thermal energy for cooling or heating, depending on the direction of current flow. Thermoelectric devices do not need refrigerants or operating fluids and their life cycle produces very few greenhouse gas emissions (Chen *et al*., 2015). This is a significant benefit for firms seeking to reduce their carbon footprint.

Doke *et al*. (2017) revealed that the thermoelectric refrigeration system is a new alternative for commercial refrigeration systems that has the advantages of being light, reliable, noiseless, rugged, and low cost in mass production, uses electrons rather than refrigerant as a heat carrier and is feasible for outdoor use in conjunction with solar photovoltaic (PV) cells, even though its coefficient of performance is not as high as for a vapor compression cycle. Thermoelectric cold storage is helpful for small and marginal farmers since it allows them to preserve items for a shorter amount of time and sell them without the product deteriorates.

Experimental evaluation of prototype thermoelectric household refrigerators was carried out by Min and Rowe (2006). Cooling performance is measured in terms of coefficient of performance, heat pumping capacity, and lowering the temperature. For a normal cooling temperature of 5°C and an ambient temperature of 25°C, the refrigerator's COP is found to be around 0.3-0.5. The results of this study's experiments revealed that by improving module contact resistances, thermal interfaces, and heat exchanger efficacy, the COP can be increased.

The thermal performance of a thermoelectric cooler is investigated experimentally with input power and cooling load variations. Three different input power variations (50.5W, 72.72W, and 113.64W) and two different cooling load utilizing mineral water (1440 mL and 2880 mL) were used in the study. At an input power of 50.5W, 72.72W, and 113.64W, the box temperature is 19.98°C, 19.77°C, and 18.52°C, respectively. The temperatures attained in the box at 1440 mL and 2880 mL cooling loads are 22.45°C and 23.32°C, respectively. The test results revealed that as the input power is increased from low to high, the temperature in the box decreases, resulting in a lower Coefficient of Performance. This is because when the input power is large, more energy can be absorbed. Because more energy is required to lower the temperature of the cooling box, the greater the cooling load delivered in the cooling box, the longer the box temperature stability attained (Mainil *et al*., 2018).

Hammad *et al*. (2017) investigated water cooling by utilizing the Peltier effect. The research work purpose was to give power to the five number of thermoelectric modules from an alternating current source by converting it to direct current power. To convert the available AC power to DC, a circuit of five transformers was designed. There were five output terminals, each with a maximum current capacity of 10 A at 12 V DC. The results indicated that by increasing the number of the thermoelectric module the performance of the system also increased.

Fabrication of thermoelectric milk cooling system

Thermoelectric module (TEC1 12715). The Peltier module (TEC1 12715) was used to design and develop a thermoelectric cooling system. The dimension of the Peltier module is 40 mm × 40 mm × 1mm. The Peltier effect governs the operation of thermoelectric coolers. By transmitting heat between two electrical junctions, the effect causes a temperature differential. To generate an electric current, a voltage is supplied across linked conductors. Heat is evacuated from one junction and cooling occurs when current travels through the junctions of the two conductors. At the other end of the circuit, heat is deposited. The Peltier effect is most commonly used for cooling. The Peltier effect, on the other hand, can be utilized to heat or control temperature. A DC voltage is required in all cases. When a current runs through one or more pairs of n-to-p-type elements, the temperature at the junction (“cold side”) drops, allowing heat to be absorbed from the surrounding environment. As electrons migrate from a high- to low-energy state, heat is transferred along with the elements by electron transport and emitted on the opposing (“hot”) side.

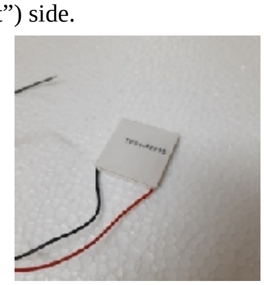

Fig. 2. TEC1 12715.

Heat sink. Heat is transferred from one end to the other using a heat sink. The heat sink is made of aluminium, which has a higher heat carrying ability. The heat sink's dimensions are 220mm × 140mm × 40mm.

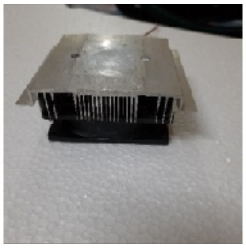

Fig. 3. Heat sink.

Fan. A fan is a device that uses a spinning arrangement of vanes or blades to move air. Impeller refers to the revolving assembly of blades and hub. Typically, fans are employed for air circulation, allowing heat from the module's hot side to disperse into the surrounding air. The fan is 90mm × 90mm × 25mm in size.

Fig. 4. Fan.

DC power supply. A switched-mode power supply (SMPS) is utilized to offer consistent current to the system because the Peltier module demands DC power (12V, 10 A).

Fig. 5. SMPS.

Experimental setup of thermoelectric water cooling system. The schematic diagram for the thermoelectric cooling experimental apparatus is presented in Fig. 6. The experimental setup consists of the following components such as Peltier module (TEC1 12715), heat sink, fan, SMPS (switched-mode power supply), and insulated stainless steel container. Heat sink paste was used to link the Peltier module's hot side to the heat sink. The module's cold side was connected to a container that held one litre of water and was used to conduct experiments. This container needed to be made of a material that could conduct heat well. To reduce heat loss, the water containers have been insulated. The heat dissipated from the hot side should be eliminated as much as possible to ensure the Peltier module's best functioning. A heat sink is fitted to the hot side of the module to dissipate the heat. A 12-volt dc fan with an aluminium finned surface makes up the heat sink. A digital thermometer and a stopwatch were used to measure the temperature and time for every 5-minute interval up to 60 minutes to determine the cooling performance of this arrangement. Fig. 7 depicts the experimental setup.

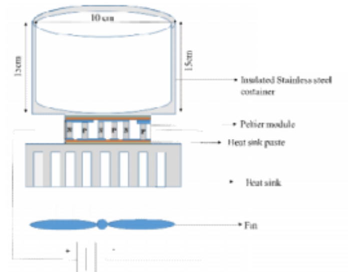

Fig. 6. Schematic diagram of thermoelectric milk cooling system.

Fig. 7. Thermoelectric cooling system.

Calculations

Refrigeration effect. The cooling load was calculated for a thermoelectric cooling system by the following formula

$$\text{Refrigeration effect } (RE) = \frac{m\,Cp\,dt}{t}$$

Where,

Where,

m = Mass of water in kg

Cp= specific heat of water kJ/ kg °C

dT = temperature difference(°C)

t = time (s)

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$$Q = \frac{1 \times 4.18 X (34.2 - 19.9)}{60 X 60}$$

$$Q = 16.3\ W$$

Power load

P = V I

P = 12 × 10= 120 W

Where,

I = current (A)

V= voltage (V)

Coefficient of performance

$$\text{COP} = \frac{RE}{P}$$

COP = 16.3 / 120 = 0.13

RESULTS AND DISCUSSION

The goal of this research work is to build a thermoelectric cooling system and examine its performance. The gathered data was then displayed and tabulated.

DISCUSSION

The Table 1 and 2 show the temperature profile and coefficient performance (COP) of the thermoelectric cooling system. It was observed that from the graph 1 to 3 plotted above, the cold side temperature and refrigeration effect of the thermoelectric cooling system was decreased with increasing time. The results coincided with Abd *et al.* (2018) who stated that the cold side temperature of the thermoelectric cooling system was decreased with increasing time. From Table 2 it was observed that the refrigeration effect of the thermoelectric cooling system was decreased due to an increase in time, a temperature difference. The results of the present study correlated with the finds of Suryawanshi *et al.* (2016) who reported that the refrigeration effect was reduced by the temperature difference of the hot side and cold side of the module with increasing time. From Fig. 10 it was observed that the coefficient of performance of the system was decreased with respect to time. The coefficient of performance of the system depends on refrigeration effect and power supply. Similar findings were observed by Venugopal *et al.* (2014) who reported that the coefficient of performance of the system varied by temperature difference, refrigeration effect and power supply.

The performance in terms of cooling temperature, refrigeration effect and COP of the thermoelectric cooling system was stabilized after 1 hour. To improve the performance of thermoelectric cooling system temperature difference (dT) between the hot side and the cold side of the module should be less. Similar findings were observed by Onarch and Chukuneke (2013) who reported that to have a maximum efficiency of thermoelectric cooling system the temperature difference should be kept as minimum as possible.The maximum refrigeration effect and C.O.P. are specified as 57.9 W and 0.48, respectively, in the initial stage.

Table 1: Temperature profile.

Time (Min)	Temperature (° C)
0	34.2
10	25.4
20	23.1
30	21.9
40	20.8
50	20.2
60	19.9

Table 2: C.O.P of thermoelectric cooling system.

Time (Minutes)	Temperature (°C)	R.E (W)	C.O.P
10	25.4	57.6	0.48
20	23.1	36.4	0.30
30	21.9	26.9	0.22
40	20.8	21.9	0.18
50	20.2	18.3	0.15
60	19.9	15.6	0.13

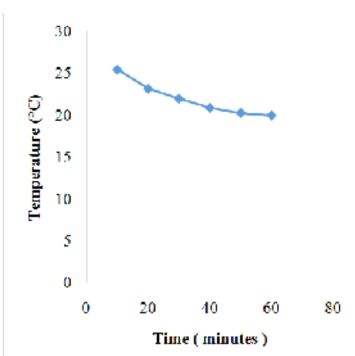

Fig. 8. Time Vs Temperature.

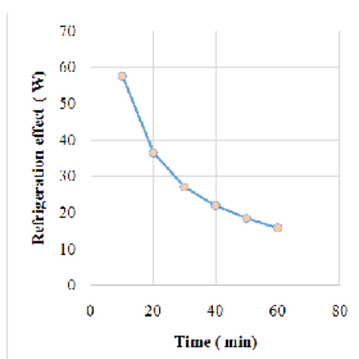

Fig. 9. Time Vs Refrigeration effect.

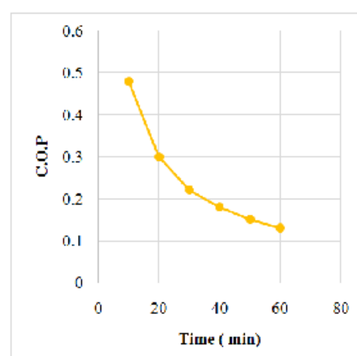

Fig. 10. Time Vs C.O.P.

CONCLUSION

We have been successfully fabricated a thermoelectric water cooling system that fulfills the proposed goals. In the present project, the maximum refrigeration effect of the fabricated system at 120W power input is observed as 57.6W and the maximum C.O.P. at the same power as 0.48. The current model, on the other hand, can only be used to reduce the temperature of a modest heat load to a specific value. We can deduct from the given facts that thermoelectric cooling systems add a new dimension to cooling. Milk and other beverages can also be chilled using thermoelectric cooling technology. It has a significant impact on the conventional system. Thermoelectric cooling systems are small in size, have no frictional parts, require no coolant, and are light in weight. Before it can be issued for effective field use, it must undergo extensive adjustments.

FUTURE SCOPE

A thermoelectric module-based cooling system has a clear approach to working as an alternative to a conventional refrigeration system. It can be integrated with the solar system thus can help in switching to a renewable source of energy. It can be very helpful in rural and remote areas where the electricity supply is not reliable. It can be used for the chilling of milk, beverages and other liquid products.

Conflicts of Interest. None.

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