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(RESEARCH ARTICLE)

Fabrication of a portable refrigerator using thermoelectric Peltier module

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Abstract

Refrigeration expending thermoelectric cooling methods have been in research for the past few decades due to its recompenses paralleled to a vapor-compression refrigerators its lack of moving parts or circulating fluid, invulnerability to leaks, small size, and flexible shape. Likewise, portable refrigerators filled with refrigerants are a big hassle to carry around along with being dangerous. This portable mini refrigerator will be capable of cooling a soft-drink canister or multiple 200 ml bottles at its prototype size and based on the results, something finer can be constructed. This attempt of us at fabricating aneco-friendly refrigerator without having to deal with the prospects of handling a dangerous refrigerant is quite affordable when mass-produced and can be installed in glove compartments of a car or a separate refrigeration compartment can be installed in a vehicle. Furthermore, these can be put into use in organizations by individuals as often as possible.

Keywords: Peltier; Refrigeration; Thermoelectric; Cooling; Temperature

1. Introduction

The term refrigeration means cooling a space, substance or system to lower and/ormaintain its temperature below the ambient one. In other words, refrigeration is artificial (human-made) cooling. The energy in the form of heat is removed from a lowtemperature reservoir and transferred to a high-temperature reservoir. The work of energy transfer is traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including household refrigerators, industrial freezers, cryogenics, and air conditioning. Heat pumps may use the heat output of the refrigeration process, and also may be designed to be reversible, but are otherwise similar to air conditioning units

2. Literature review

Hongxia Xi, Lingai Luo et al [1] State in their publication that Energy crisis has always been a majorissue for the world. As energy demand is escalating day by day, everyone necessitate appliances that use less amount of energy because conventional appliances i.e. refrigerators and heaters consume large amount of power ranging from 200W to 1500W. Proposed model is based on Peltier effect, and uses Peltier module (TEC1- 12706) which exhibit cooling at one side plate and heating on other one depending upon supply voltage biasing. For improving heating effectiveness Fresnel lens heat collector concept is also used. So in energy saving context, a model is proposed which can be used for heating as well as cooling purpose and draw less amount of energy. Simon Lineykin et al [2] In his paper discusses a domestic refrigerator which incorporates in its interior a device to make ice cubes using thermoelectric technology has been developed. For its design a computational model has been implemented. This model solves both thermoelectric and heat transfer equations including the phase change equations. The inputs are the thermoelectric parameters as a function of the temperature and the boundary conditions: (room temperature and voltage supplied to the Peltier module). The outputs are the values of the temperature for all the elements of the thermoelectric ice-maker and the ice

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production. Tian-Hu Wang et al [3] Published matters concerning a number of prototype thermoelectric refrigerators are investigated and their cooling performances evaluated in terms of the coefficient- of- performance, heat-pumping capacity and cooling-down rate. The coefficient-of- performance of a thermoelectric refrigerator is found to be around 0.3–0.5 for a typical operating temperature at 5 °C with ambient at 25 °C. The potential improvement in the cooling performance of a thermoelectric refrigerator is also investigated employing a realistic model, with experimental data obtained from this work. The results show that an increase in its COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers. Navdeep Jakhar et al [4] State in their publication that Energy crisis has always been a major issue for the world. 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The inputs are the thermoelectric parameters as a function of the temperature and the boundary conditions: (room temperature and voltage supplied to the Peltier module). The outputs are the values of the temperature for all the elements of the thermoelectric ice-maker and the ice production Gao min et al [6] Published matters concerning a number of prototype thermoelectric refrigerators are investigated and their cooling performances evaluated in terms of the coefficient-of-performance, heat-pumping capacity and cooling-down rate. The coefficient- of- performance of a thermoelectric refrigerator is found to be around 0.3–0.5 for a typical operating temperature at 5 °C with ambient at 25 °C. The potential improvement in the cooling performance of a thermoelectric refrigerator is also investigated employing a realistic model, with experimental data obtained from this work. The results show that an increase in its COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers. Mayank awasthi et al [7] Address the issues of global warming and confers that the global increasing demand for refrigeration in field of refrigeration air-conditioning, food preservation, vaccine storages, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 all over the world which it is contributing factor of global warming on climate change. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in meeting today‘s energy challenges. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed. Ahmet Caglar [8] In this study, a portable mini thermoelectric refrigerator driven by a Peltier element is designed, constructed and tested. The Peltier element combined with fans on both sides is mounted onto a refrigerator box. An optimization for the operating conditions of the thermoelectric refrigerator is performed. The operating conditions of the system are the ambient temperature and voltages of the fans and Peltier element. Performance analysis for the optimum conditions obtained is presented. M.Mirmanto et al [9] Performed an experimental performance investigation on thermoelectric cooler box with several positions of the thermoelectric was performed. The cooling system of the cooler box comprised a thermoelectric module model TEC1-12706, a heatsink-fan, an inner heat sink, a bottle of water with a volume of 360 ml. The positions of the thermoelectric were at the top, on the bottom, and on the wall. Dai et al [10] Have designed and developed a thermoelectric refrigeration system powered by solar cells generated DC voltage and carried out experimental investigation and analysis. They developed a prototype which consists of a thermoelectric module, array of solar cell, controller, storage battery and rectifier. The system with solar cells and thermoelectric refrigerator is used for outside purpose in daytime and system with storage battery, AC rectifier and TER is used in night time when AC power is available. Experimental analysis on the unit was conducted mainly under sunshine conditions. The studied refrigerator can maintain the temperature in refrigerated space at 5–10^{o}C, and has a COP about 0.3 under given conditions Wahab et al. [11] Designed and developed an affordable thermoelectric refrigerator powered by solar cells generated DC voltage for the desert people living in Oman where electricity is not available. In this study the researchers used 10 nos. of thermoelectric module in design of refrigerator. The finned surface (heat sink) was used to enhance and increase the rate of heat transfer from the hot surface of thermoelectric module. Cooling fan was used to reject the heat from the hot side of module to ambient surroundings. The experimental data collected from running one thermoelectric module indicate that it is possible to achieve temperature difference upto 26.6^{o}C at current 2.5 A and voltage 3.7 V. The coefficient of performance of the refrigerator was calculated and found to be about 0.16. Putra [12] Designed, manufactured and tested a portable vaccine carrier box employing thermoelectric module and heat pipe. The position of heat pipe as a heat sink on the hot side of the TEM enhanced the cooling performance. The minimum temperature in the vaccine carrier cabin reached -10oC, which shows that vaccine carrier can store the vaccine at desired temperature Adeyanju et al [13] Carried out a theoretical and experimental analysis of a thermoelectric beverage chiller. Comparison were also made between the thermoelectric beverage chiller‘s cooling time with cooling times obtained from the freezer space and cold space of a household refrigerator. The result shows that for the refrigerator freezer space, the temperature of the water decreased linearly with increasing time and for thermoelectric beverage chiller the temperature of the water decreased exponentially with increasing time. Lertsatitthanakorn et al [14] Evaluated the cooling performance and thermal comfort of a thermoelectric ceiling cooling panel (TE-CCP) system composed of 36 TEM. The cold side of the TEM was fixed to an aluminum ceiling panel to cool a test chamber of 4.5 m3 volume, while a copper heat exchanger with circulating cooling water at the hot side of the TE modules was used for heat release. Thermal acceptability assessment was performed to find out whether the indoor environment met the ASHRAE Standard-55‘s 80% acceptability criteria. The standard was met with the TE-CCP system operating at 1 A of current flow with a corresponding cooling capacity of 201.6 W, which gives the COP of 0.82 with an average indoor temperature of 27oC and 0.8 m/s indoor air velocity. Gillott et al. [15] Conducted an experimental investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings. They performed a theoretical study to find the optimum operating conditions, which were then applied in the laboratory testing work. A TEC unit was assembled and tested under laboratory conditions. Eight pieces of Ultra TEC were shown to generate up to 220W of cooling effect with a COP of 0.46 under the input current of 4.8A for each module. Bansal et al [16] Conducted a detail study on energy efficiency and cost-effectiveness for vapour compression, thermoelectric and absorption refrigeration of similar capacity (about 50 liter). The investigated result show that vapour compression refrigerator was the most energy efficient (with a COP of 2.59) followed by thermoelectric (COP of 0.69) and absorption refrigerator (COP of 0.47). The Cost analysis results show that the total purchasing and operating costs over the life of the systems was the lowest for the vapour-compression unit at NZ$506, followed by the thermoelectric ($1381.2) and the absorption refrigerator ($1387.4). The researchers finally concluded that the VC refrigerator was the most energy efficient and cheaper unit followed by the thermoelectric and the absorption refrigeration. Optimization process are used to enhance the efficiency [17-25].

3. Methodology

The major components of the thermoelectric refrigerator include thermoelectric module, aluminum tin, MDF sheetss, finned surface (or heat sink), and the cooling fan. In this study, single thermoelectric module was used in the design of the refrigerator. A battery, which stores electricity the form of chemical energy. The module and fan is connected to the battery. The entire set up is assembled in a wooden box with nuts and bolts. The module is placed such that hot side faces the heat sink and a spacer block placed on the cold side of the module by applying thermal grease. The fan is studded to the heat sink to reject the extra heat. A aluminum container is insulated by polystyrene. Cooling transfers from module to spacer block and container. for measuring the temperature in the container a thermos couple is connected to digital meter.

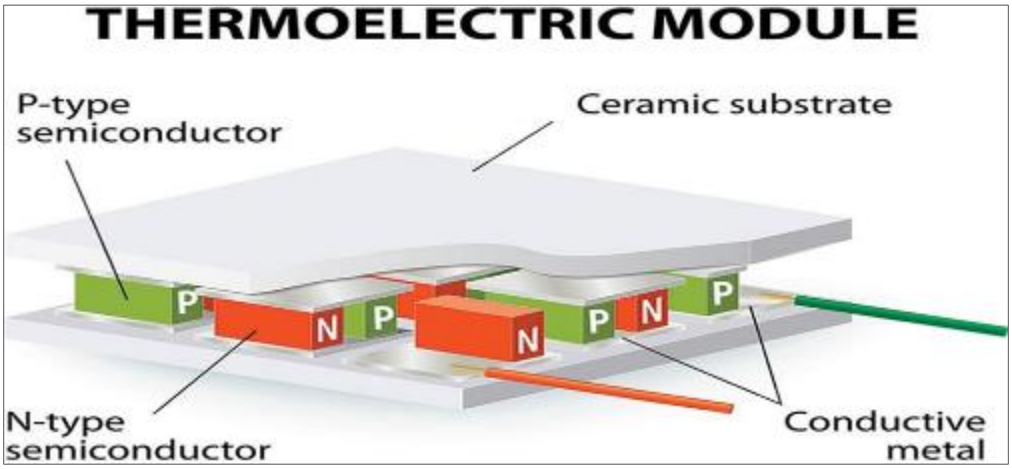

Figure 1 Thermoelectric Module

The components are connected together in testing the operation of the thermoelectric module. The red wire of the thermoelectric module is connected with the positive power supply (i.e., solar cells) and the black wire of the module is connected with the negative power supply. Due to this method of wire connection, the lower surface of the thermoelectric module became the hot side of the module, while the other side became the cold side of the thermoelectric module. The cold side of the thermoelectric module is needed to be set inside the refrigerator and the hot side to be set outside. The temperatures of the hot and cold sides of the thermoelectric module were measured by thermocouple wires which were connected to the sides of the module. One end of the thermocouples was connected to the hot side of the module whereas the other end was connected to the cold side. The thermocouple was connected to a data logger so the electric current was converted and recorded in temperature units. The hot side of the thermoelectric module was attached to the heat sink whereas the cold side of the thermoelectric module was used to cool the refrigerator cabinet. The heat sink was attached to the hot side of the thermoelectric module to release heat more efficiently out into the atmosphere. The back side of the heat sink was connected with the fan that was used mainly to help in rejecting the extra heat out into the atmosphere. It can be seen that the temperature of the cold side of the thermoelectric module will decrease and the temperature of the hot side of the thermoelectric module will increase.

Conclusion

$$Q(rej) = (m*cp*dT)/t$$

M=mass Cp=specific heat
ΔT=change in temperature
T =time

$$Q(rej\ ratio))= 100th\ time\ of\ Q(rej)$$

$$COP = 1/(1-Q(rej\ ratio))$$

Peltier module Surface area = L*W
Length = 40 mm
Width = 40 mm
Peltier module Surface area = 40*40
Volume of the box = L*W*H
L = length
W = width
H = heigth
Outer Volume of the box = 10.5*8*8.5 i3
Inner Volume of the box = 9.5*7*7.5(6 lit)
Solar panel dimentions for 12 v output =164*99

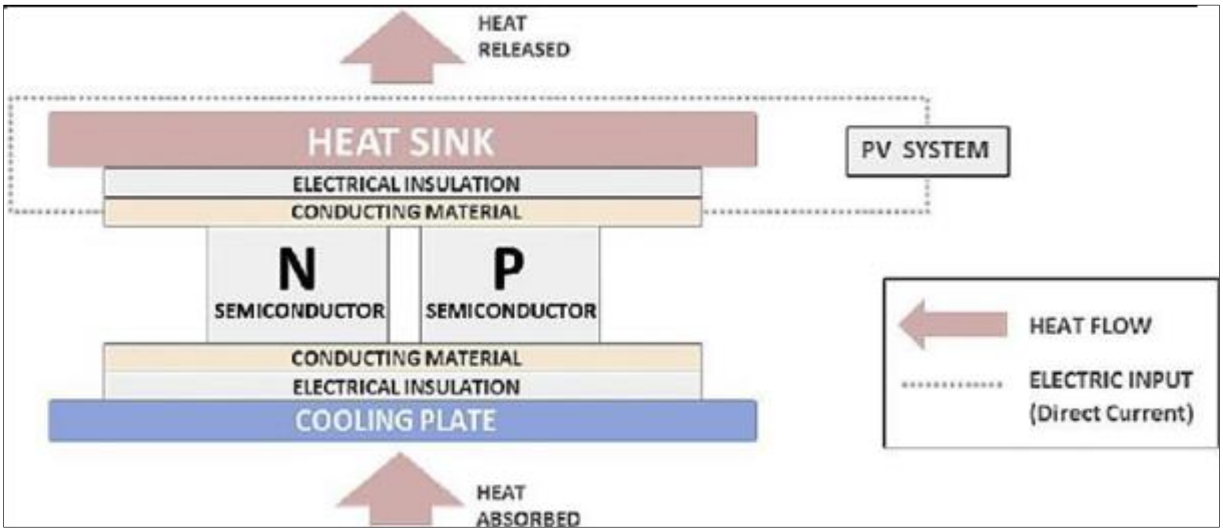

Figure 2 Simplified Scheme of TE Module

3.1. Refrigeration research

The history of artificial refrigeration began when Scottish professor William Cullensmall refrigerating machine in 1755. Cullen used a pump to create a partial vacuumcontainer of diethyl ether, which then boiled, absorbing heat from the surrounding air. In 1758, Benjamin Franklin and John Hadley, professor of chemistry, collaborated on a project investigating the principle of evaporation as a means to rapidly cool an object at Cambridge University, England. They confirmed that the evaporation of highly volatile liquids, such as alcohol and ether, could be used to drive down the temperature of an object past the freezing point of water. They conducted their experiment with the bulb of a mercury thermometer as their object and with a bellows used to quicken the evaporation; they lowered the temperature of the thermometer bulb down to −14 °C (7 °F), while the ambien temperature was 18 The experiment even created a small amount of ice but had no practical application at.°C (65 °F). The noted that soon after they passed the freezing point of water 0 °C (32°F), a thin film of ice formed on the surface of the thermometer's bulb and that the ice mass was about 6.4 millimeters (1/4 in) thick when they stopped the experiment upon reaching −14 ° (7°F). Franklin wrote, "From this experiment, 10 one may see the possibility of freezing a man to death on a warm summer's day".

In 1805, American inventor Oliver Evans described a closed vapor-compression refrigeration cycle for the production of ice by ether under a vacuum.In 1820 the English scientist Michael Faraday liquefied ammonia and other gases by using high pressures and low temperatures, and in 1834, an American expatriate to Great Britain, Jacob Perkins, built the first working vapor-compression refrigeration system in the world. It was a closed-cycle that could operate continuously, as he described in hi patent: am enabled to use volatile fluids to produce the cooling or freezing of fluids, and yet at the same time constantl condensing such volatile fluids, and bringing them again into operation without waste.‖ His prototype system worked although it did not succeed commercially. In 1842, a similar attempt was made by an American physician, John Gorrie, who built aworking prototype, but it was a commercial failure. Like many of the medical experts during this time, Gorrie thought too much exposure to tropical heat led to mental and physical degeneration, as well as the spread of diseases such as malaria. He conceived the idea of using his refrigeration system to cool the air for comfort in homes and hospitals to prevent disease. American engineer Alexander Twining took out a British patent in 1850 for a vapor compression system that used ether.

The first practical vapor-compression refrigeration system was built by James Harrison, a British journalist who had emigrated to Australia. His 1856 patent was for a vaporcompression system using ether, alcohol, or ammonia. He built a mechanical ice-making machine in 1851 on the banks of the Barwon River at Rocky Point in Geelong, Victoria, and his first commercial ice-making machine followed in 1854. Harrison also introduced commercial vapor-compression refrigeration to breweries and mea packing houses, and by 1861, a dozen of his systems were in operation. He later entered the debate of how t compete against th American advantage of unrefrigerated beef sales to the United Kingdom. In 1873 he prepared the sailing ship Norfolk for a experimental beef shipment to the United Kingdom, which used a cold room system instead of a refrigeration system. The venture was a failure as the ice was consumed faster than expected. The first gas absorption refrigeration system using gaseous ammonia dissolved in water 11 (referred to as "aqua ammonia") was developed by Ferdinand Carre France in 1859and patented in 1860. Carl von Linde, an engineer specializing in steam locomotives and professor of engineering at the Technologica University of Munich in Germany, began researching refrigeration in the 1860s and 1870s in response to demand from brewers for a technology that would allow year-round, large-scale production of lager; he patented an improved method of liquefyi gases in 1876. His new process made it possible to use gases such as ammonia, sulfur dioxide ($SO2$), and methyl chloride ($CH3Cl$) as refrigerants, and they were widely used for that purpose until the late 1920s.

In 1913, the first electric refrigerators for home and domestic use were invented and produced by Fred W. Wolf of Fort Wayne, Indiana, with models consisting of a unit that was mounted on top of an ice box.[11][12] His first device, produced over the next few years in several hundred units, was called DOMELRE.[13][14] In 1914, engineer Nathaniel B. Wales of Detroit, Michigan, introduced an idea for a practical electric refrigeration unit, which later became the basis for the Kelvinator. A self-contained refrigerator, with a compressor on the bottom of the cabinet was invented by Alfred Mellowes in 1916. Mellowes produced this refrigerator commercially but was bought out by William C. Durant in 1918, who started the Frigidaire company to mass-produce refrigerators. In 1918, Kelvinator company introduced the first refrigerator with any type of automatic control. The absorption refrigerator was invented by Baltzar von Platen and Carl Munters from Sweden in 1922, while they were still students at the Royal Institute of Technology in Stockholm. It became a worldwide success and was commercialized by Electrolux. Other pioneers included Charles Tellier, David Boyle, and Raoul Pictet. Carl von Linde was the first to patent and make a practical and compact refrigerator.

These home units usually required the installation of the mechanical parts, motor and compressor, in the basement or an adjacent room while the cold box was located in the kitchen. There was a 1922 model that consisted of a wooden cold box, water-cooled compressor, an ice cube tray and a 0.25-cubic-metre (9 cu ft) compartment, and cost $714. (A 1922 Model-T Ford cost about $476.) By 1923, Kelvinator held 80 percent of the market for electric refrigerators. Also in 1923 Frigidaire introduced the first self-contained unit. About this same time porcelain-covered metal cabinets began to appear. Ice cube trays were introduced more and more during the 1920s; up to this time freezing was not an auxiliary function of the modern refrigerator.

4. Result and discussion

Thermoelectric cooler is usually used for temperature control tools, for example, scientific instruments for electronic and optoelectronic systems. Sometimes it is also used in precise temperature instruments for example to cool the laser temperature and infrared detectors. Therefore, it is very convenient to build small-scale thermoelectric cooling machines for these applications.

Therefore, in this study, we have constructed a mini thermoelectric refrigerator as shown in figure. The study also comprises of computer simulation using the governing equations. To illustrate the movement of energy from inside the cooler to the outside, a thermal resistance circuit had been illustrated in figure . The mini thermoelectric cooler contains an internal heat sink, a thermoelectric model and an external heat sink. R1 and R2 are the internal and external heat sink resistance. To design a mini Peltier cooler, it is essential to know the design requirement such as the amount of heat removed from the internal heat sink,external electric power, W is to be applied to the TEC to flow the energy from a low temperature to a high temperature. The performance of the mini cooler is assessed by the coefficient of performance (COP). The COP is a function of heat rejection ratio Q(rej). Q(rej) is a function of (m(mass)*cp(specific heat)* ΔT (change in temperature)) divided by the time(t) .

$$Q(rej) = (m*cp*dT)/t$$

We have taken the mass and cp values of water as the preferred liquid into considerations.

M of water in 5lit volume = 5kg
Cp of water = 4.186 kj/kgk
dT(change in temperature) => (45- 28) =17
t (time) => 5min = 300sec
Q(rej) = (5*4.186*17)/300
Q(rej) = 1.186
COP = 1/(1-Q(rej ratio))
COP = 1/(1- 0.01186)
COP = 1.012

Figure 3 Fabricated model of the mini refrigerator

5. Conclusion

A mini Peltier cooler was fabricated by using a thermoelectric Peltier cell coupled with fancoole heat sinks. The use of Peltier thermoelectric module has the big potential to replace th oversized conventional vapour refrigeration in designing a mini cooler for specific applications The objective of this study is to design, fabricate and to validate a model of the min thermoelectric cooler tha operates in the actual conditions. This study consisted of modelling theoretical background of the Peltier cooler to predict its performance. For the theoretical modelling, the temperature difference between the internal space of the cooler box and th ambient were firstly assumed. The assumed value was used in the simulation to predict the h and cold temperatures of the Peltier cell surfaces.This value is essential in predicting the Peltier cooler performance such as the coefficient of performance (COP) and the heat removal from th mini cooler.The study was followed by designing, fabricating and testing of the mini coole prototype. For the actual testing, the ambient temperature, the internal and external ai temperatures of the foam box and hot temperature and cold temperature of the plate wer measured. The experimental data gathered in the testing were used to validate the theoretica model. It was found that the error between the experimental and simulation data were less tha 1% which ensured the validity of the model. The testing results showed that the internal coole box temperature drops significantly more than 10°C from its original temperature befor reaching a steady state temperature Meanwhile, the measured cold surface temperature of the Peltier cell extremely slumped t lower than 28° while the hot surface temperature peaked up to higher than the ambien 3 temperature at 45°C. This big temperature gradient created across the thermoelectric cel surfaces showed the effectiveness of the Peltier effect. In term of performance, the min cooler was capable of giving the 1.012 coefficient of performance (COP). The cooler CO was found above than the previous study by other researchers There are few recommendations for future study could be made to enhance the min cooler performance: To use better performance passive heat sinks for heat dissipation such a heat pipe heat sink. To use active cooling liquid heat sink for removing external heat from th Peltier module. To use high- performance Peltier cell. To use high conductivity therma interface material for linking the heat sinks and the Peltier cell.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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