



Fabrication and Performance Analysis of a Multipurpose Thermoelectric Refrigeration System

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ABSTRACT

In this study, a portable Multipurpose thermoelectric refrigeration System 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 voltage of the fans and Peltier element. Performance analysis for the optimum conditions obtained is presented.. The optimum ambient temperature is 303 K. Results also show that the cooling COP of the system decreases from 0.251 to 0.011 while the temperature of the cooled space changes from 303 K to 289K and 303K to 343K in hot cabin. The proposed thermoelectric refrigerator is used to keep drinks, foods or medicines fresh and cool. And we can use this as a drier.

Keywords : Thermoelectric cooler ; Peltier element ; Fan ; Optimization ; Performance Analysis

1.Introduction

Researches on energy-efficient green technologies and conversion of waste heat into useful work are being accelerated in order to reduce environmental issues such as global warming and pollution. Now a days , The conversion of energy is as important as its generation due to the energy demand increasing inevitably. One of attractive subjects on green conversion of energy is thermoelectric (TE) device that can be powered by renewable energy source such as PV cells. Despite commonly used in cooling applications, TE devices can also be used in heating applications. Furthermore, electricity power can be generated by maintaining a temperature difference between the surface of TE device using Seebeck effect. According to (1.Study on performance 2021) In this they noticed that conventional refrigeration system makes noise which gives negative impact .So They are trying to avoid this by coupling the thermoelectric modules with ionic wind fans .The new system will give quite operation with optimum voltage consumption .The use of TE devices is principally preferred for its advantages of silent operation, long lifetime, being compact and environment-friendly, having no moving parts and no working fluid, requiring smaller spaces and no maintenance. On the other hand, their applications are limited due to the lower energy conversion efficiencies with respect to the other common systems 2.(Solar based Thermoelectric...2022) Refrigerator using the Peltier effect to maintain a specified temperature, perform temperature control in the range of 5C to 25C also authors explained how it will be ecofriendly.(3.Performance and ...2020) A novel design of a portable solar thermoelectric refrigerator is proposed in this study. he cooling effect of the thermoelectric module is utilized to provide cooling to the refrigerator space from (4.CFD analysis for .. 2020) In this journal they work on Computational Fluid Dynamics(CFD) analysis was conducted considering three different turbulence models.The cooling time was observed 144min for getting cooling of around 10 degree Celsius. Simulation analysis of TEC modules is done in this paper. Seebeck (1826) discovered the TE effect which is the conversion of temperature difference between dissimilar

metals to an electric current. Peltier (1834) proved the feasibility of Seebeck effect inversely such that the current applied is converted to a temperature gradient.

(5.Performance..2021) In this study, a novel building envelope integrated with thermoelectric cooler and radiative sky cooler (TEC-RSC) was proposed, not only for the elimination of heat gain through itself but also for space cooling. Through optimization design, the TEC-RSC can provide a cooling capacity of 25.49 W/m² with a COP of 2.00 under the condition of global solar radiation.

In this study, the validation of TEC model and that of RSC model were conducted, respectively, to confirm the effectivity of the TEC-RSC model.(7.Design..2022) The objectives of this study is design and develop a working thermoelectric refrigerator interior cooling volume of 18L

that utilizes the Peltier effect to refrigerate and maintain a temperature from 33 °C to 22 °C. The design requirements are to cool this volume to temperature within a time period of 1hr and to obtain COP in the range of 0.2 to 0.6.(9.Improvement..2017) The working parameters of thermoelectric refrigeration system are greatly affected by the operating voltage and the cooling efficiency. The design is to increase of fin area and fan speed to improve its cooling capacity.The main problem over the use of TEC is the limited COP and its thermal performance. But these can be eliminated by use of multistage thermoelectric cooler.(10.Performance analysis..2018) This study experimentally investigates the performance of the single stage and multistage TEC air-cooling module. It is quite easy to achieve the significant temperature difference in the single stage TE module, but, the COP of the single stage module is very less for the domestic use.In the multistage TE module, It is possible to get the require COP as well as better thermal performance.(13.Experimental..2020) This paper reports the experimental analysis of a novel hybrid sorption-compression chiller for cooling and refrigeration purposes in cascade layout, which uses silica gel/water for the sorption cycle and a low

Global Warming Potential (GWP) refrigerant, i.e. propylene for the compression cycle. (14.Performance..2020)A novel design of a portable solar thermoelectric refrigerator is proposed in this study. The cooling effect of the thermoelectric module is utilized to provide cooling to the refrigerator space.(15.Theoretical..2021) This paper aimed at obtaining the optimal cooling performance of the thermoelectric refrigeration box system. Three groups of experiments comprised of 17 working conditions were conducted, depending on the fullscale experiments.

(16.Design..2012) In this Journal they noticed that conventional refrigeration system makes noise which gives negative impact .So They are trying to avoid this by coupling the thermoelectric modules with ionic wind fans. (17.Performance..2013) In this Journal they noticed that TEC is a versatile component that is very compact in size as compared to a compressor-based system that works on the Peltier principle.(18.Performance..2020) A novel design of a portable solar thermoelectric refrigerator is proposed in this study. The cooling effect of the thermoelectric module is utilized to provide cooling to the refrigerator space.(19.Theoretical..2017)In this journal they work on Computational Fluid Dynamics(CFD) analysis was conducted considering three different turbulence models.(20.Experimental..2017) In this study, a novel building envelope integrated with thermoelectric cooler and radiative sky cooler (TEC-RSC) was proposed, not only for the elimination of heat gain through itself but also for space cooling.(21.Experimental..2020) In this article, an aggregation strategy is proposed to fulfil system operator requests on power deviations with limited information exchange between the aggregator and each refrigerator.(22.Numerical..(2019) In this article, three dimensional numerical simulations have been performed for the optimization design of a compact TEC .(23.Solution..2017) This paper focuses on the potential of exploiting thermoelectric cooling as an interesting option to be applied in a refrigeration.(24.Theoretical..2017)

This paper aimed at obtaining the optimal cooling performance of the thermoelectric refrigeration box system.

Table 1

Summary of results obtained in recent studies on TECs.

Reference	TEC technology/model	Hot side/Cold side heat sink	COP
(Manikandan et al., 2017)	Modified pulse operation of 24 TECs in series	Natural convection/ Natural convection	1.01
(Gokcek&Sahin, 2017)	Single TEC/TEC1-12709	Minichannel, forced water/Forced air	0.18
(Astrain et al., 2016)	96 TECs in parallel/Marlow DT12-8L	Forced water/Air; Heat Pipe/Air; Air/Air	0.42-0.77
(Qian and Ren, 2016)	Transverse TEC	-/-	0.59-1.50
(Martinez et al., 2016)	Two TECs in series/Marlow RC12-6L	Forced air/Natural convection	0.09-0.33
(Hu et al., 2016)	Single TEC/TEC1-26315	Forced water/CPU (electric heater simulated)	0.5-1.4
(Wang et al., 2015)	Two-stage TEC in series	-/-	0.33
(Ohara et al., 2015)	Single TEC/Laird PT 40	Forced air/Planar heat pipe	0.3
(Jeong, 2014)	Single TEC	-/-	1.1

Optimization studies on the subject are generally based on theoretical or numerical models although they include investigations on both operational and design (or geometric) parameters. There is a lack of optimization study performed using experimental methods. On the other hand, there is a limited number of researches on thermal performance of TE refrigerator at varying fan powers at both sides of TE material although some similar studies on the effects of varying TE currents exist in the literature. Additionally, there is no document regarding the effect of ambient temperature as an operational parameter. In this study, a TE refrigerator that works based on Peltier effect is designed and constructed. The TE refrigerator is tested for different rotational speeds of fans and different working powers of the Peltier device as well as different ambient temperatures. They are all the operating conditions that influence the performance of the system. Using the results of the experiments, an optimization for the operational conditions that maximize the COP of the system is performed. The investigation of the COP variation of the TE refrigerator with different fan speeds (or powers) and optimization of a TE refrigerator are the originality and novelty of this study.

2. Material and method

2.1 Working principle of Peltier element



Figure 2.1



Figure 2.2

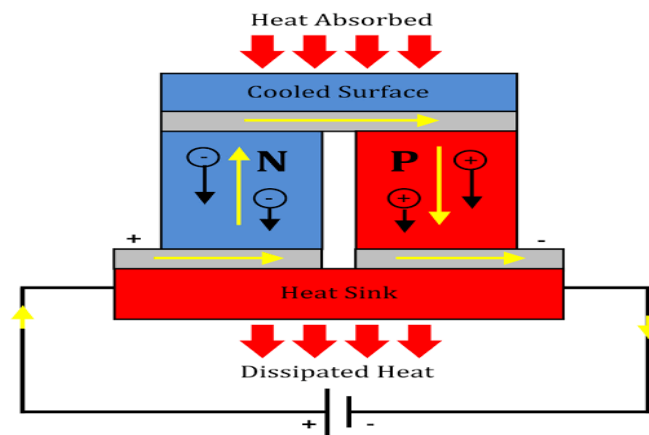


Fig. 2.3 Principle of peltier effect

A Peltier element can be used for heating and cooling or generating electricity. Two different semiconductors called N- and P-type semiconductors are welded to a conductor, usually copper, on both sides. The semiconductors are sandwiched between the copper plates coated by ceramic layers for electrical insulation. Electrons can travel freely in the copper conductors but not so freely in the semiconductors. As the

electrons leave the copper conductor and enter the hot side of the P-type, the electrons fill a hole in order to move through the P-type and they drop down to a lower energy level and therefore release heat to the hot side. As the electrons move from the P-type into the conductor on the cold side, they are bumped back to a higher energy level and absorb heat from the cold side. Same process occurs for the N-type semiconductor. Thus, a temperature difference is occurred by circulating an electric current through the junction of two different semiconductors. The degree of heating or cooling is predominantly determined by the type of semiconductor metal (generally bismuth telluride) used in the production of Peltier element.

2.2 Experimental Setup

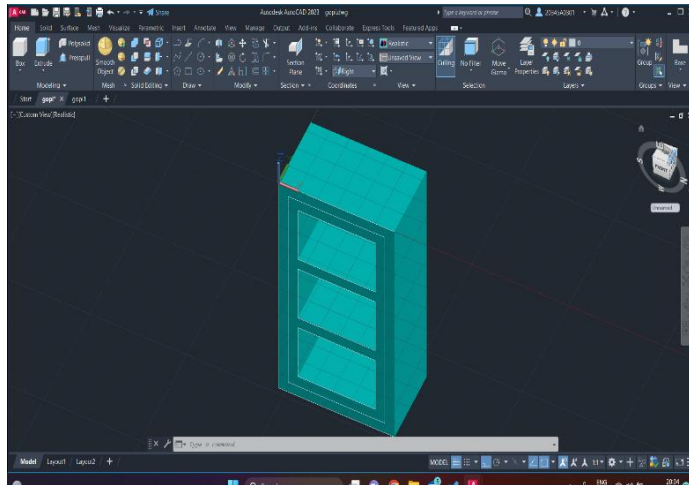


Fig.2.4Autocad 3D modeling of prototype

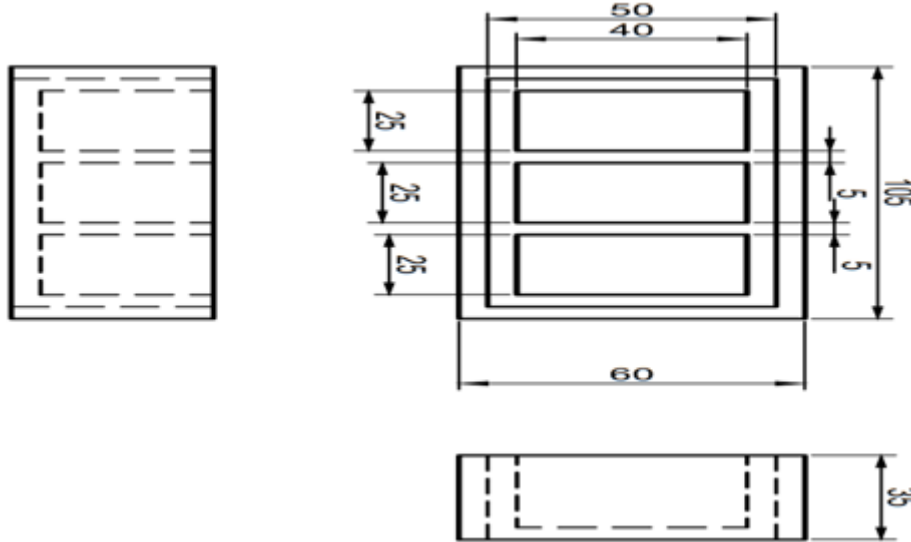


Fig 2.5 Interior body of Thermoelectric refrigeration system

Table no 2.1: Outer dimensions of TEC set up

s.no	Dimesion	Value in cm
1	Length	105
2	Breadth	60
3	Width	35

Inner dimensions of the each cabin

Table no 2.2: Dimensions of water cooling cabin

S.no	Dimesions	Value in cm
1	Height	30
2	Length	60
3	Width	35

Table no 2.3: Dimensions of air cooling cabin

S.no	Dimesions	Value in cm
1	Height	30
2	Length	60
3	Width	35

Table no 2.4: Dimensions of drier cabin

S.no	Dimesions	Value in cm
1	Height	30
2	Length	60
3	Width	35

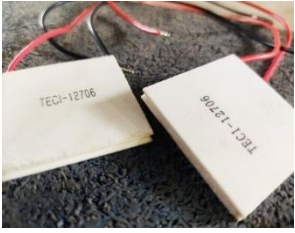
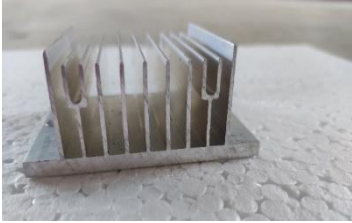



The TE refrigeration system consist of a Peltier device, Insulated box with dimensions 105x60x30 cm (0.189 m³ volume), plate-fins (heat sinks), Submergible Pump , Transparent tray (40x19x22 cm), axial fans. The plate-fins and axial fans are mounted on both sides of the TE device to dissipate heat easily. The hot side of TE device must be cooled well in order to obtain low temperatures on the cold side. Because of this, a fan is usually used on the hot side of TE devices. On the other hand, a fan on the cold side is optional and used to blow the cold air into the box and obtain a uniform temperature inside the box. The current installation direction of the fans is chosen due to the better heat transfer performance with respect to the inverse installation direction according to initial test results. Both fans have 12 V input voltage, but the outer fan (i.e., the fan on the hot side of the Peltier element) is more powerful and has higher amperes than the inner fan (i.e., the fan on the cold side of the Peltier element). The fins (heat sinks) are made of aluminum.

2.3 Materials and Measurement devices used

A digital Multimeter used to measure the working voltage and current of fans. Digital temperature sensors are used to measure the temperatures

at four points inside the refrigerator box. Four temperature sensors measures cooling water temperature inside the water tray while the other thermocouple measures the air temperature in the hot cabin , one more is used to measures the temperature air cooling chamber

Table 2.5

Sl.NO	Component	Specifications	Quantity
1.		<ul style="list-style-type: none"> • Current=6A • 127 Couples • Voltage – 12V • Semiconductor 	5 Nos.
2.	 Heat Sink	<ul style="list-style-type: none"> • Aluminium • Protrusion design 	5 Nos.
3.	 Cooling Fan	<ul style="list-style-type: none"> • Voltage 12v • Current 5A • BLDC 	5Nos.
4.	 Rectifier	<ul style="list-style-type: none"> • AC to DC • Voltage -12V • Current -5A 	2Nos.
5.	 Thermopaste	<ul style="list-style-type: none"> • 5gm 	2Nos.

6.	 <p>Submersible Pump</p>	<ul style="list-style-type: none"> • Current=6A • Voltage – 12V • Discharge : 10L/min 	1No.
7.	 <p>Digital Temp. Sensor</p>	<ul style="list-style-type: none"> • +150 degree to -10 degrees 	4Nos.
8.	 <p>Aluminum Sheet</p>	<ul style="list-style-type: none"> • 150cm X 120cm 	1No.
9.	 <p>Rectangular bar</p>	<ul style="list-style-type: none"> • AC to DC • Voltage -12V • Current -5A 	1No.
10.	 <p>Transperant water tray</p>	<ul style="list-style-type: none"> • 40cm x 22cm x 19cm 	1No.
11.	 <p>Electric wire</p>	<ul style="list-style-type: none"> • 3m wire 	1No.

2.4 Experimental Procedure

Before starting an experiment, the voltages of the fans and Peltier element are adjusted and recorded. The experiment is started when all the temperatures measured are in equilibrium with the ambient temperature. Temperature measurements are recorded at 3-minute intervals. The period for an experiment is 60 minutes. This period is selected due to that steady state conditions are observed after about 60 minutes. The temperature of the air inside the TE refrigerator is taken as the average of the four temperature measurements.

3. Optimization of Operational conditions

Table 3.1 Experimental Results of water cooling

S.No	Time (Min)	Temperature (°C)
1	0	34
2	10	28.2
3	20	25.5
4	30	24
5	40	21.9
6	50	20.2
7	60	18.6

Table 3.2 Experimental COP Results of water cooling

S.No	Time (Min)	Temperature(°C)	Refrigeration effect(W)	C.O.P
1	10	28.2	121.2	2.020
2	20	25.5	88.82	1.480
3	30	24	69.66	1.161
4	40	21.9	63.22	1.053
5	50	20.2	57.68	0.961
6	60	18.6	53.64	0.894

4. Results and Conclusion

After doing the experiments based on the results we are plotting the below graphs

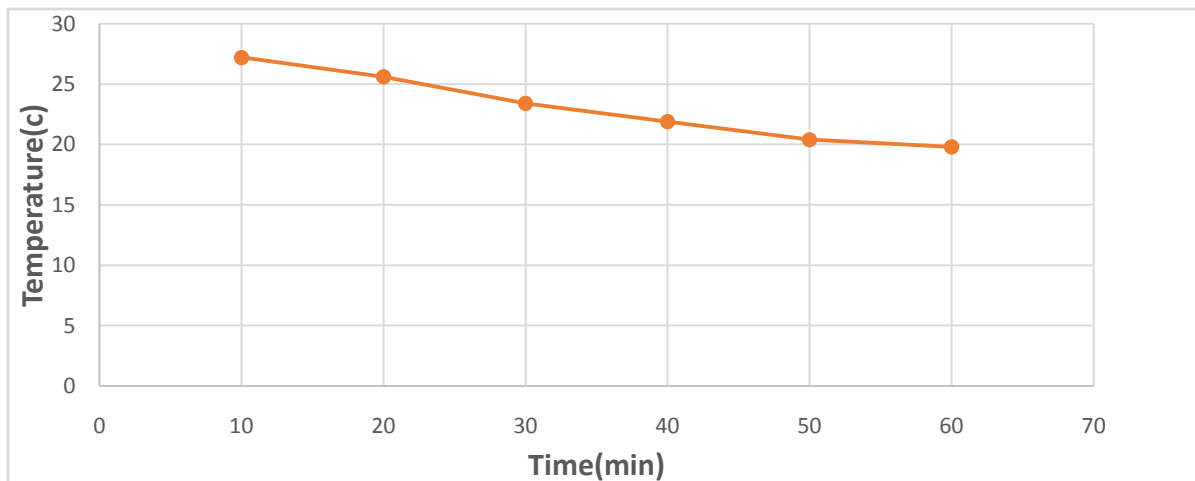


Fig 4.1 Time Vs Temperature

Based on the above behavior of the graph we can easily said that by the gradual increasing of the time the temperature of the system will be decreasing . In the span of 60 min it will decrease maximum upto 20 degrees.

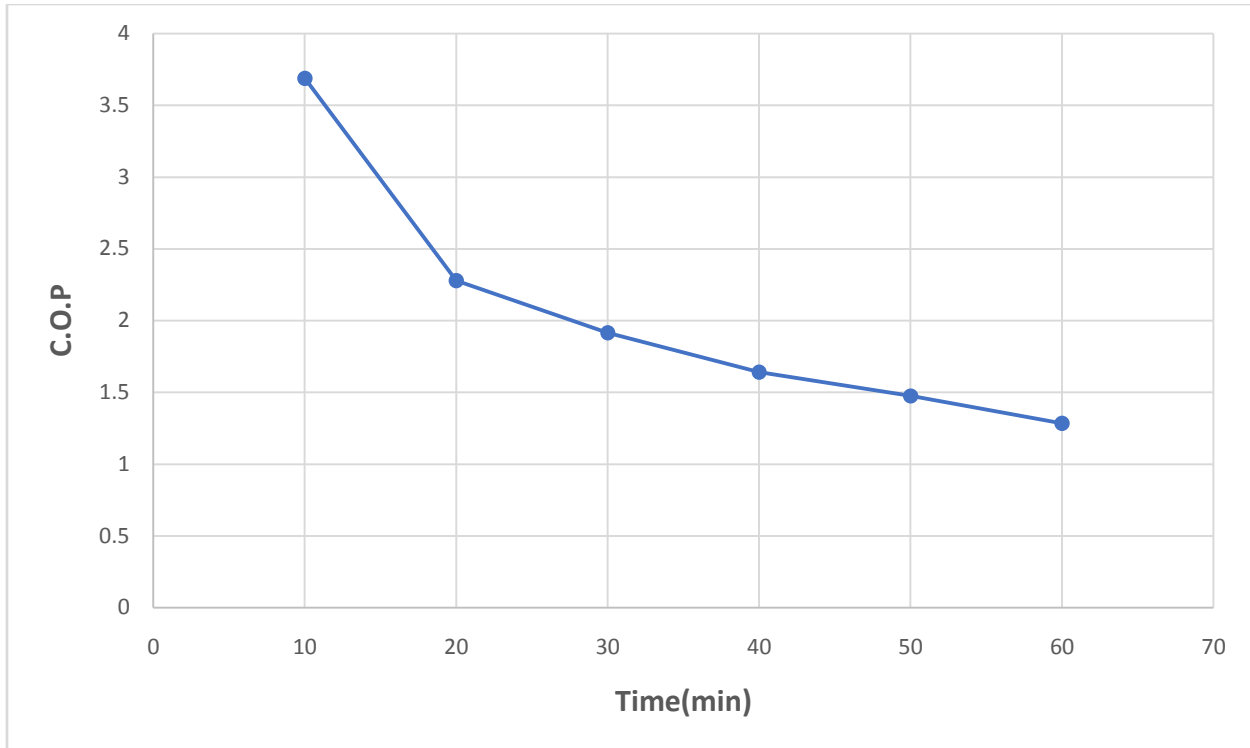


Fig 4.2 Time Vs C.O.P

By this we can conclude that by the gradual increasing of time the COP of the system will be decreasing slightly initially it will be higher the it is decreasing because of the over increasing the time the power consumption will be increased so that the cop will be degraded.

Conclusion:

- The overall maximum cooling temperature we can achieve in this system is 16°C
- The maximum temperature we can achieve on hot side is around 70°C
- In the system we were achieved average COP of 0.216
- The main benefit of this is we can use multiple purposes like water cooling, Air cooling, Air drying in single unit , So that the overall efficiency is increased.

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