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Experimentation and Fabrication of a Thermoelectric Water Dispenser.

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Abstract — The recent rise in the environmentally harmful pollution has given rise to scientific study on different fields that would give us the idea of saving the planet earth to some extent. The refrigerant used in convectional systems is one of the most alarming things of all. The emission of CFC's has given a rise to the depletion of ozone hence harming our eco-system as we speak. This research aims to reduce the use of refrigerant by an alternative system usage. The convectional refrigerant can be exchanged for a thermoelectric peltier module that can also generate Cooling. Literature survey carried out led to problem statement that the refrigeration time would be terribly high but the cooling would be effective. Hence the aim was to experimentally analyze the performance of thermoelectric module by putting it into an application that would render useful for recent years to come.

Index Terms—Thermoelectric Module, Glass Tank, COP, Hot Side, Cold Side, Max Cold Side Temp, Max Hot Side Temp, Efficiency, Current, Voltage, Peltier Effect.

1.)Introduction

Fossil fuels are the ones that are considered as non-renewable energy sources. Researches on Alternative energy technologies have made humans to reduce fossil fuel consumption. Although these fossil fuels are still a necessity they are as well as eradication for the planet that we live in. One of the research topics that have become increasingly interesting in recent years is thermoelectric (TE) elements. TE effect is a phenomenon in which a temperature difference or heat transfer occurs due to the passage of electric current through a junction between two different semiconductors, and vice versa. TE elements have the advantages of being environment-friendly, compact, need of lesser space, long life, no moving parts, silent operation and less maintenance requirement. In 1822, German physicist See-beck discovered a magnetic field, which could turn a compass needle, and correspondingly an electric field occurred between two different metals held at different temperatures. Peltier observed that this effect was also in the opposite direction, that is, when a voltage is applied to different metals, the cooling performance of TE cooler has been investigated by several authors in different modes experimentally and theoretically.

TE cooling system integrated with phase change material (PCM) for space cooling such that PCM stored cold thermal energy at night and functioned as a heat sink to reduce hot side temperature of TE modules during day-time cooling period and thus increased the COP of the system from 0.5 to 0.78. An experimental performance analysis of mini-channel water cooled-TE refrigerator for different voltages and flow rates was presented. In another study on water-cooled TE cooler, effect of water mass flow rate on performance is investigated using temperature control strategies under severe environment for prevent condensation and saving energy. An efficient thermoelectric distillation system was designed and constructed for production of drinkable water. An application of a direct evaporative cooling system for improving the performance of a compact TE air conditioner, they achieved 40.6% increase in the cooling capacity, and 20.9% increase in the COP. Transverse TE devices, on the other hand, can produce thermoelectric effects in which the electrical and thermal flows are perpendicular to one another. Cooling performance of a hypothetical transverse TE device and concluded that transverse refrigerators might offer higher cooling capacity with some sacrifice in COP when compared to their longitudinal Counter parts.

S.No.	Symbols	Quantity	Units
1.	Q	Heat Removed from the water.	J
2.	m	mass	Ltr
3.	Cp	Specific Heat	KJ/Kg/°C
4.	V	Voltage	volts
5.	I	Current	Amp.
6.	h2	Convective heat transfer coefficient of water	$W/(m^2K)$
7.	h1	Convective heat transfer coefficient of air.	$W/(m^2K)$
8.	T1	Initial temp of water	°C
9.	T2	Final temp of water aft exp	°C
10.	T_{inf2}	Temp of water surrounding the inner surface	°C
11.	T_{inf1}	Ambient air temp surrounding the outer surface of water tank	°C
12.	T_{s1}, t_1	Outer surface temp of water tank	°C
13.	T_{s2},t_2	Inner Surface temp of tank	°C
14.	A	Area	m
15.	K	Thermal Conductivity of Glass	W/(m·K)
16.	L	Thickness of Glass wall of Water Tank.	m

Table 3.8 – Nomenclature. [13]

2) Experimental Setup and Methods.

2.1) Experimental Setup

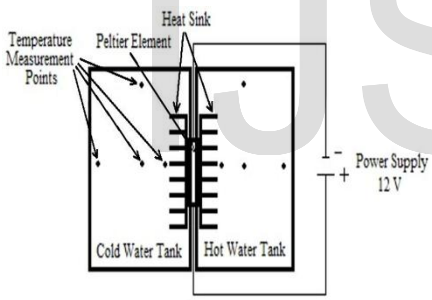

Fig 1: Experimental Setup [2]

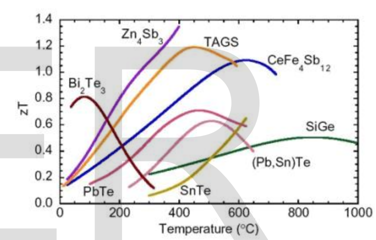

Fig. 2: p-type thermoelectric materials [13]

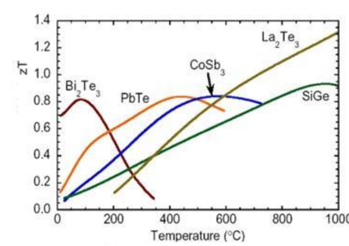

Fig. 3: For n-type thermoelectric materials [13]

2.2) METHODS

2.2.1) Design Considerations and Selection of Components

2.2.1.1)Selection Criteria and Specifications of Thermoelectric Circuit

Various combination of semiconductors like bismuth telluride, lead telluride, silicides, oxide thermoelectric, silicon germanium, sodium cobaltite, etc. are used in the peltier cooling but as per the graphs, Thus we are selecting a standard as well as optimal selection as per the cost of thermocouple.

Moreover, Fig 3.4. Shows that the COP increase with increasing the current up to certain value then it further decreases, i.e. there existed an optimum current at particular high Voltage when all other parameters have been kept constant.

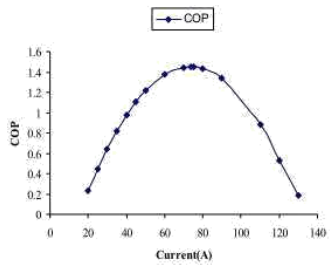

Figure 4 Variation of COP with current [13]

Table 3.1 Variation of COP at various values of current

Current (A)	COP	Current (A)	COP
20	0.228941	70	1.445937
25	0.446404	73.64	1.451433
30	0.642586	75	1.450592
35	0.817488	80	1.433967
40	0.977111	90	1.336873
45	1.103449	110	0.887316
50	1.214508	120	0.524852
60	1.372784	130	0.182389

Influence of input power on COP can be observed from the Fig 3.4. It is seen that the COP decreases with increase in input power. This happens as increase in voltage leads to rise in current; hence more heat is being transferred at the hot end that results in lower the cold end temperature. From these data it has been observed that as the current increases the COP increases upto a certain level where the increase in voltage leads to decrease in output.

Table 3.2 Variation of COP at various values of voltage

Input power (V)	COP
1.09463404	0.9419188
1.368292551	0.753535
1.641195106	0.6279459
1.915609571	0.5382393
2.189268081	0.4709594
3.283902121	0.3139729
4.030442537	0.2558172
4.378536162	0.2354797
6.02048722	0.171258

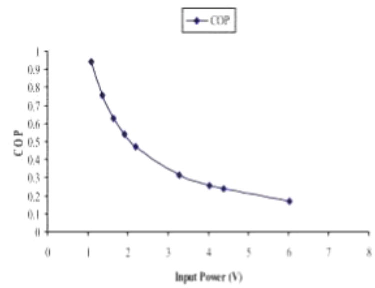

Figure 5 Variation of COP with voltage [13]

Thus we are selecting a standard voltage of 12 V and one module of 6 Amp current capacities the readings taken for different quantity of water will be helpful to select the module of required capacity. The specifications of modules of 15 A and 6 A are given below.

Table 3.3 Thermoelectric module specifications

Operational voltage	12 V DC
Current mass	6 Amp/15 Amp
Voltage max	15.4 Volts
Power max	92.4/120 Watt
Power nominal	60/100
Couples	127
Types of semi-conductor	Bismuth telluride
Dimensions	40 x 40 x 3.5 mm

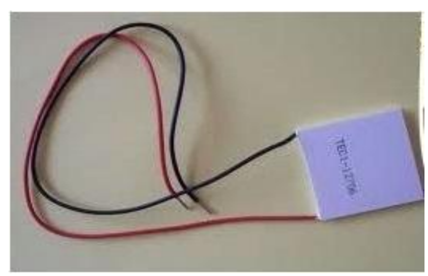

Fig. 6 Thermoelectric Module (TEC1-12706) [13]

2.2.1.2) Selection Criteria and Specifications of Heat sink:-

The selection of proper fan and heat sink plays an important role in the heat dissipation process. The material of heat sink is aluminum as it is available easily and has more thermal conductivity which is useful in more heat transfer which will lead to lower temperature difference. In this research work more hot side temperature is required so it is very necessary that maximum heat should be rejected from the system. The specifications of the fan and heat sink for 1 litre capacity for 6 A and 15 A are given below.

Selection Criteria and Specifications of Heat Sink:-

Heat sink plays an important role in cooling the water. The number of fins, the dimensions and shape of the fins and the material used decides the performance of the fins. Aluminum or copper can be used due to their excellent thermal conductivity as well as they are easily available and cost effective. Aluminum is selected as the heat sink material due to its low cost. Below specifications are given for the fins used for 6 A and 15 A modules.

Detailed study revealed that aluminum is not available as a food grade and thus stainless steel (SS-304) was selected as a fin material so that the water remains hygiene and safe for drinking. Thus, in the final module of 20 A, fins of stainless steel are used.

Table 3.5 Heat Sink Specifications

Thickness Of Fins	2 mm
Material	Stainless Steel
Size	60 x 60 x 20 mm
No. Of Fins	8

Fig.7 Heat Sink

2.2.1.3) Selection Criteria and Specifications of Water Container

Initially for simplicity plastic material was selected for a small container and for final container stainless steel was selected. Plastic material of considerable thickness of around 3mm having very low thermal conductivity, which is beneficial for the cooling phenomenon. Specifications for both the containers are given below.

Table 3.6 Water Container specifications

Material	Glass
Shape	Cuboid
Thermal Conductivity	1 W/mk
Capacity	1 Litre

Fig. 8 Water container

2.2.1.4) Switched Mode Power Supply

A switched-mode power supply (SMPS) is an electronic circuit that converts power using switching devices that are turned on and off at high frequencies, and storage components such as inductors or capacitors to supply power when the switching device is in its non-conduction state.

Figure 9 SMPS [13]

2.2.1.5) Thermocouple

A suitable Thermocouple is selected according to the temperature range specified by the catalogue given by the manufacturer.

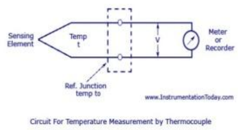

Fig. 10.Thermocouple

Table 3.7. Specifications for Thermocouple

Range	-270 °C and 370 °C
Error	+/- 0.5°C or 0.4%
Accuracy	± 0.5 °C

2.3) Observations

Experimentation starts at 11:31 am

Room Temperature - 28° C

Water Temperature – 25.8° C

Observation Table

Time	Temperature (°C)	
	Hot Water	Cold Water
12:01 pm	26.4	23.1
12:32 pm	29.4	21.9
01:01 pm	32	21
01:31 pm	33.6	20.5
02:01 pm	34.9	20.2
02:31 pm	35.5	20
03:01 pm	36.7	19.6
03:31 pm	37.2	19
04:01 pm	38.5	18.3
04:31 pm	39.8	17.1

2.4) Equations & Calculations

2.4.1) Equations

1.) Heat removed from water (Q).

$$Q = (m) * (cp) * (T1 - T2)$$

2.) Qcooling = Q / Time req.

3.) Power Input = (V * I)

4.) Qpassive = h2A(Ts1 – Tinf2) + KA(T1 – T2) / L + h1A(Ts1 – Tinf1)

5.) QT = Qcooling + Qpassive

6.) COP = QT / Power supply

2.4.2) Calculations

FOR COLD SIDE

3 litre water was cooled from t_1 = 25 ˚C to t_2 = 17.1 ˚C in duration of 5 hours. The hot side and cold side temperatures were Th = 39.8 ˚C and Tc = 17.1 ˚C respectively. Ta = 28 ˚C. Thus,

Heat removed from water,

$$Q = m\ Cp\ (t_1 - t_2)$$

$$Q = 3 * 4.184 * (25.8 - 17.1)$$

$$Q = 109203\ J$$

Time required for cooling = 5 hours.

$$Q_{cooling} = Q / Time\ req.$$

$$Q_{cooling} = 109203 / 5*60*60$$

$$Q_{cooling} = 6.07\ J / Sec$$

Power Input (P) = (V * I)

$$P = 12 * 1.8$$

$$P = 21.6\ W$$

$Q_{passive}$ (For Long Side)

$= h2A (T_{s1} - T_{inf2}) + KA (T_1 - T_2) / L + h_1A (T_{s1} - T_{inf1})$

= 50*(0.0349)*(17.8 – 17.1) + ((1*0.0349)*(18.5 - 17.8)) / (0.015) + 10*0.0349 (18.5 - 28)

= (-0.466) W

$Q_{passive}$ (For Small Side)

$= h2A (T_{s1} - T_{inf2}) + KA (T_1 - T_2) / L + h_1A (T_{s1} - T_{inf1})$

= 50*(0.0233)*(17.8 – 17.1) + ((1*0.0233)*(18.5 - 17.8)) / (0.015) + 10*0.0233*(18.5 - 28)

= (-0.3784) W

$Q_{passive}$ = Qpassive (For Long Side) + $Q_{passive}$ (For Small Side)

$Q_{passive}$ = (-1.086) W

$Q_T = Q_{cooling} + Q_{passive}$

= 6.07 + (-1.086)

= 4.984 J / Sec

COP = Q_T / Power supply

COP = 4.984 / 21.6

COP = 0.23074

FOR HOT SIDE

3 litre water was heated from t_1 = 25.8 ˚C to t_2 = 39.4 ˚C in duration of 5 hours. The hot side and cold side temperatures were Th = 39.8 ˚C and Tc = 17.1 ˚C respectively. Ta = 28 ˚C. Thus,

Heat added to water,

$$Q = m\ Cp\ (t_1 - t_2)$$

$$Q = 3 * 4.184 * (39.8 - 25.8)$$

$$Q = 175728\ J$$

Time required for cooling = 5 hours.

$$Q_{heating} = Q / \text{Time req.}$$

$$Q_{heating} = 175728 / 5*60*60$$

$$Q_{heating} = 9.78\ J / Sec$$

Power Input (P) = (V * I)

P = 12 * 1.8

P = 21.6 W

$Q_{passive}$ (For Long Side)

$= h2A (T_{s1} - T_{inf2}) + KA (T_1 - T_2) / L + h_1A (T_{s1} - T_{inf1})$

= 50*(0.0349)*(37.5 – 28) + ((1*0.0349)*(38.2 - 37.5)) / (0.015) + 10*0.0349 (38.2 – 38.9)

= (17.962) W

$Q_{passive}$ (For Small Side)

$= h_2A (T_{s1} - T_{inf2}) + KA (T_1 - T_2) / L + h_1A (T_{s1} - T_{inf1})$

= 50*(0.0233)*(37.5 – 28) + ((1*0.0233)*(38.2 - 37.5)) / (0.015) + 10*0.0233*(38.2 – 38.9)

=(-74.84) W

$Q_{passive}$ = Qpassive (For Long Side) + $Q_{passive}$ (For Small Side)

$Q_{passive}$ = (11.992) W

$Q_T = Q_{heating} + Q_{passive}$

= 9.78 + (41.946)

= 51.726 J / Sec

COP = Q_T / Power supply

COP = 51.726 / 21.6

COP = 2.4

3) Result and Discussion

3.1) Result

1.) COP of HOT side = 2.4

2.) COP of COLD side = 0.23

3.2) Discussion

After the calculations we have got the result as shown above. The COP of HOT side is 2.4 and COP of COLD side is 0.23. We can say that the thermoelectric module (TEC1-12706) is not giving the expected efficiency and it can be used as a temporary solution not as a permanent solution in the industry or in daily routine. The expectation from the module was to give max temperature range between 40 degree Celsius to 45 degree Celsius and for min temperature ranges between 10 degree Celsius to 15 degree Celsius but unfortunately it didn't gave the expected values. The human body can consume cold water up-to 14 degree Celsius and Hot water up-to 45 degree Celsius and we were experimenting for drinking purpose. There was a big effect of room temperature on the system as it not properly fabricated before experimenting but the temperature change totally depends upon the room temperature, if the room temp is high then the efficiency towards hot side is more or room temperature is low then the efficiency is more toward the cold side. It can be used by the bachelors living alone to save electricity but it consumes more time as compared to the other cooling or heating systems. The power supply given to the module was 4amp to 6amp current and 12 volts voltage to work in which it gave us max temperature 40 degree Celsius and min temperature 17 degree Celsius. So after the discussion we can say that the module we choose (TEC1-12706) to analyze the efficiency is not capable to work and we should think on using other module.

For Example – TEC1-12715, 12720, 12705.

4 Conclusion

Hence it came to light that, a thermoelectric module requires electricity for heat generation and it can also be used for heat rejection that will result in space cooling. Many researchers has studied that thermoelectric module has quite an effective temperature range but our application was for drinking purpose so we had to increase the temperature range so that an average human would be able to consume cold as well as hot drinking water Hence we increased the quantity from 1 to 2 thermoelectric modules to increase the temperature range. After experimenting and studying we came to know that the TE module had given us near about the temperature range that we desired. But further to increase the efficiency it can be made effective by increasing the no. of thermoelectric module and by providing the insulation to the tank.

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References

1.) Google and Wikipedia.

2.) M. Gökçek, F. Sahin, Experimental performance investigation of mini channel water cooled thermoelectric refrigerator, Case Studies in Thermal Engineering, 10 (2017), pp. 54–62.

3.) H. Al-Madhhachi, G. Min, Effective use of thermal energy at both hot and cold side of thermoelectric module for developing efficient thermoelectric water distillation system, Energy Converse. Manage. 133 (2017) 14–19.

4.) W. He, J. Zhou, J. Hou, C. Chen, J. Ji, Theoretical and experimental investigation on a thermoelectric cooling and heating system driven by solar, Appl. Energy 107 (2013) 89–97.

5.) H.M. Hu, T.S. Ge, Y.J. Dai, R.Z. Wang, Experimental study on water-cooled thermoelectric cooler for CPU under severe environment, Int. J. Refrig. 62 (2016) 30–38.

6.) V.P. Joshi, V.S. Joshi, H.A. Kothari, M.D. Mahajan, M.B. Chaudhari, K.D. Sant, Experimental investigations on a portable fresh water generator using a thermoelectric cooler,
energy Procedia, 109 (2017), pp. 161–166.

7.) S.B. Riffat, X. Ma, Thermoelectrics: a review of present and potential applications, Appl. Therm. Eng. 23 (2003) 913–935.

8.) W. Tipsaenporm, C. Lertsatitthanakorn, B. Bubphachot, M. Rungsiyopas, S. Soponronnarit, Improvement of cooling performance of a compact thermoelectric air conditioner using a direct evaporative cooling system, Journal of Electronic Materials, 41 (6) (2012), pp. 1186–1192.

9.) S. Twaha, J. Zhu, Y. Yan, B. Li, A Comprehensive review of thermoelectric technology:
Materials, applications, modelling and performance improvement, Renew. Sust. Energy Rev. 65 (2016) 698–726.

10.) B. Qian, F. Ren, Cooling performance of transverse thermoelectric devices, Int. J. Heat Mass Transf. 95 (2016) 787–794.

11.) H.M. Hu, T.S. Ge, Y.J. Dai, R.Z. Wang, Experimental study on water-cooled thermoelectric cooler for CPU under severe environment, Int. J. Refrig. 62 (2016) 30–38.

12.) L. Shen, Z. Tu, Q. Hu, C. Tao, H. Chen, The optimization design and parametric study of thermoelectric radiant cooling and heating panel, Appl. Therm. Eng. 112 (2017) 688–697.

13.) Y. Zhou, J. Yu, Design optimization of thermoelectric cooling systems for applications in electronic devices, Int. J. Refrig. 35 (2012) 1139–1144.

14.) Valiulla Hadiya Atif, Design and Development of dual application of heating and cooling using thermoelectric technology, Thermal Eng. LDRP-ITR, Gandhinagar (2018) 382015.