FABRICATION AND PERFORMANCE EVALUATION OF THERMOELECTRIC CHILLER BOX

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ABSTRACT: The paper discusses the study of Peltier performance on cooling of chiller box. To increase efficiency of Peltier liquid cooling can be incorporated so as to obtain a silent cooling operation. Peltier module has been majorly employed in active heat generating equipment cooling so to keep the temperature to a precise level. The TEC/Peltier is basically p-type and n-type of semiconductor which are arranged in series such that whenever current is applied to its terminal one of the side of module gets colder and other side gets hot. The major drawback of the Peltier is its limited efficiency and thermal performance.

KEYWORD: Thermoelectric Cooler, TEC, Peltier, Liquid Cooling, Chiller Box

Peltier module is also known as thermoelectric cooling module. It mainly works on Peltier-Seebeck effect as shown in figure 1. This effect describes that whenever a low voltage direct current is applied to module the heat is pumped from one side to that of other side. In contrast to that of mechanical refrigeration system also known as Vapour Compression System work on basic thermodynamic principle. The Peltier module is also governed by the same principle but in different manner but within accordance of same principle. The mechanical refrigeration system consists of compressor, refrigerant, evaporator, and condenser. All these equipment works together so as to achieve the required cooling. In Vapour Compression System, the compressor compresses refrigerant so as to raises its pressure which then flows to condenser where it losses heat and then flow through an expansion valve which eventually reduces the pressure during the flow in evaporator where is gains heat from the system, thus cooling it. Whereas in contrast to this system Peltier is a solid state drive which doesn't have any moving parts just work by the heat pumping action of p-type and n-type semiconductor. The Peltier is just fixed with heatsink on both of its side so as to absorb and dissipate heat. It may be provided with fan so as to increase air circulation throughout the system thus increasing the heat removal process, which will eventually increase the cooling efficiency of the Peltier module. But air circulation does not provide that much of heat dissipation that is required by the system so various other system can also be applied so for the purpose of heat dissipation which mainly included Vapour Chamber cooling and Liquid cooling. In all of the above heat dissipation methods liquid cooling provides superior results.

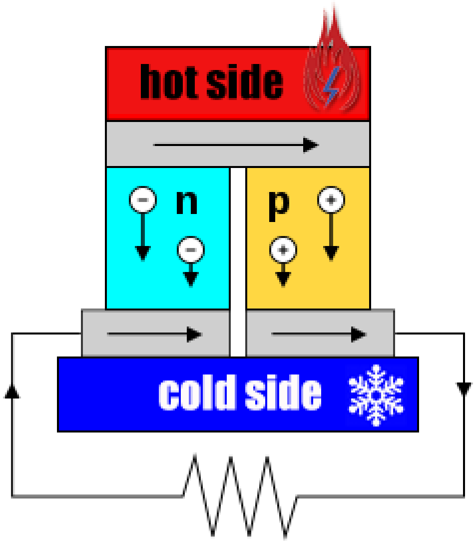


Figure 1 : Seebeck Effect (Source:https://tegmart.com/info/wp-content/uploads/2018/04/seebeck-effect.png)

The major point to consider in Peltier cooling is the amount of heat removed from the system, higher the removal higher is the COP but due to its performance constrain and reduced COP it cannot be utilized in industrial or domestic uses. But recent development has increased the overall efficiency of Peltier but not up to that extent. The calculation of COP can be expressed as

$$COP = \frac{Q_c}{W_{in}}$$

This COP- Coefficient of Performance provided an idea about how well is the Peltier module is working. So this calculation evolves as an integral part of system especially in designing any refrigeration system.

CONSTRUCTION

The chiller box is made up of plywood which was lined by thermocol lined in the inner side of it, another layer of aluminium sheet also lines the thermocol. The thermocol provides a layer of insulation to the whole chamber whereas aluminium sheet provides the surface to spread the heat throughout the storage area. The chiller box also consists of a liquid cooling system which is used for the dissipation of heat from the Peltier hot side. A temperature sensor module was also installed so as to measure the temperature of different parameter that may be required for the proper measurement.

ABBREVIATION

I	Current
COP	Coefficient of Performance
K	Thermal Conductivity
Q_H	Heat Rejection
Q	Heating and Cooling Rate
R	Electrical Resistance
Q_L	Heat Absorption
T	Temperature
T_h	Hot Side Temperature
T_c	Cold Side Temperature
TEC	Thermoelectric Cooler
S	Seebeck Coefficient
ΔT	Temperature Difference
P	Power Consumption
BiSn	Bismuth Tin Alloy

TEC SPECIFICATION

In the model TEC-12706 was installed with the following specification

T_h(°C)	27	50
ΔT_{max}(°C)	70	79
V_{max} (Voltage)	16	17.2
I_{max} (A)	6.1	6.1
Q_{cmax} (Watts)	61.4	66.7
AC Resistance (ohms)	2	2.2
Tolerance	±10%	
No. of thermocouple	127	
Dimension	40 mm x 40 mm x 3.8 mm	

The temperature of thermoelectric device was done at hot side, cold side, storage box and coolant temperature. The whole operation of thermoelectric cooling was done on single stage.

THERMOELECTRIC COOLER MODULE

The thermoelectric cooler module was made up of BiSn. The properties of 127 BiSn thermocouple 6A module TEC-12706 are

Seebeck Coefficient (S) = 0.01229 V/K

Module Thermal Resistance (K) = 0.1815 W/K

Module Resistance (R) = 4 Ω

METHODOLOGY

THERMAL ANALYSIS

The thermal analysis has been conducted on thermoelectric module. The heat rejection of the Peltier side is called Q_H and the heat absorbing side of Peltier is known as Q_L. According to literature, the general form of heat absorption and heat rejection can be expressed as presented below. Heat transferred into cold side without acknowledging temperature drop through the Peltier is given by:

$$Q_L = [SIT_c - \frac{1}{2}I^2R - k(T_h - T_c)]$$ (-) sign for heat rejection

While heat transfer through heat sink from the hot side is:

$$Q_H = SIT_h + \frac{1}{2}I^2R - k(T_h - T_c)$$

Both of Seebeck effect and resistance depends upon the material used within the TEC, it is majorly governed by the geometry of module as well as dimension of n-type and p-type semiconductors.

COP of Single Stage TEC

$$COP = \frac{Q_L}{Energy\ Supplied\ (W)}$$

CALCULATION

A dimensionless criterion is known as Coefficient of Performance or COP is used here to calculate the performance of the Peltier module used in this thermoelectric based cooling chiller machine. COP can be defined as the ratio of thermal output power and the electrical input power of the Peltier module. COP is calculated by dividing the amount of heat absorbed at the cold side of the Peltier module to the input power.

$$COP = \frac{Q_L}{Energy\ Supplied\ (W)}$$

Here, in the above equation-

$$Q_L = -[SIT_C - \frac{1}{2}I^2R - k(T_h - T_C)]$$

And energy supplied-

$$W = Q_H - Q_L$$
$$= SI(T_H - T_C) + I^2R$$

The following table shows the readings-

Serial No.	Time in Minutes	Temperature at Cold Side of Peltier Module In °C	Temperature at Hot Side of Peltier Module In °C	Storage Chamber Temperature In °C	Liquid Coolant Temperature In °C
1	0 min	31	31	31	29
2	10 min	15.7	37.8	29.8	32
3	20 min	12.4	42.5	27.2	34.7
4	30 min	10.9	45	22.4	35.1
5	40 min	8.1	47.4	18.1	35
6	50 min	5	48.9	15	35.1
7	60 min	2.6	50.7	12.6	35.2
8	70 min	-1.2	51.4	10.7	35.2
9	80 min	-3.4	53.2	8.8	35.3
10	90 min	-5	55	7.5	35.4

Based on the above readings the calculation of COP can be done.
Therefore,

$$Q_L = -[SIT_C - \frac{1}{2}I^2R - k(T_h - T_c)$$

Here,
I= 2.6 Amp
T_h= 55°C= 328K
T_c=-5°C= 268K
Therefore, from the above readings-

$$Q_L = -\Big[0.01229 * 2.6 * 268 - \frac{1}{2} * 2.6^2 * 4 - 0.1815 * (328 - 268)\Big]$$

Q_L=15.84 W

And,

$$Q_H = [SIT_H + \frac{1}{2}I^2R - k(T_h - T_C)]$$

$$Q_H = \Big[0.01229 * 2.6 * 328 + \frac{1}{2} * 2.6^2 * 4 - 0.1815 * (328 - 268)\Big]$$

Q_H=13.11W

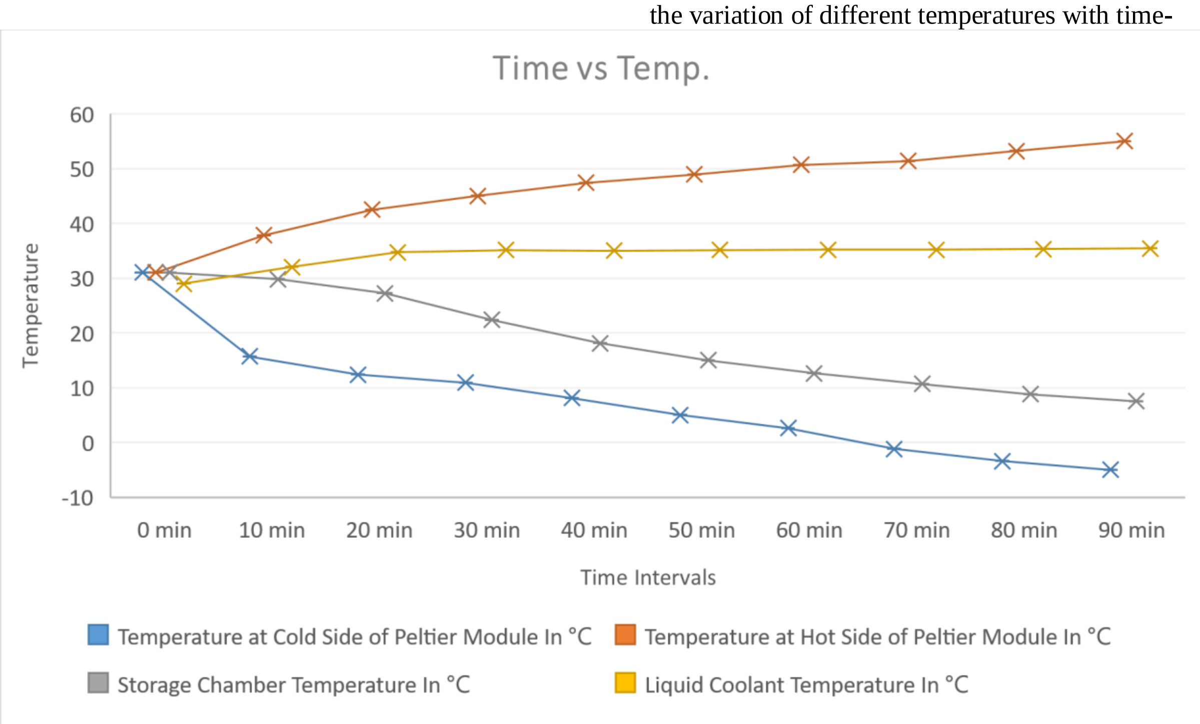
Therefore,

$$W = Q_H - Q_L$$
$$W = 13.11 + 15.84$$
$$[(-)\ sign\ for\ Q_L\ is\ for\ heat\ absorption]$$
$$W = 28.95W$$

Now,

$$COP = \frac{Q_L}{Energy\ supplied\ (W)}$$
$$COP = \frac{15.84}{28.95}$$
$$COP = .54$$

Below is the Temperature vs Time graph showing the variation of different temperatures with time-



CONCLUSION

It can be said that thermoelectric cooling has added a whole new field in the cooling technology. With the use of this thermoelectric cooling, reduction in temperature can be improved to enhance performance, reliability and reduction in the overall cost. Thus, it can be said that in the coming future thermoelectric cooling can replace the vapour compression cooling and it has proved itself to be a worthy potential candidate for this. Here, a thermoelectric cooling-based chiller machine has been designed and fabricated to maintain the temperature of the storage at a range of 5-10℃. Here, we do a experimental analysis to study the performance of a thermoelectric module or more commonly known as Peltier module. It is easy to achieve a good temperature drop and temperature difference in a Peltiermodule, but, the COP of the Peltier module is not very impressive. Also, the cost of the thermoelectric module is significantly high. But, with the ongoing research and recent development in the field of thermoelectric cooling and with the application of nanoscience to its benefit, different thermoelectric substances with significant temperature difference and low cost are being studied. These studies will further contribute to the benefit of thermoelectric cooling and in the future, we can see more advancement in this field.

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