A Review on Thermoelectric Cooler

Akshay Phalke[1], Shirish Pawar[1], Arnav Pokharkar[1], Kaustuv Saikia[1],J.S. Khot[2]
[1]Department of Mechanical Engineering, Smt. Kashibai Navale College of Engineering, Pune-41
[2]Assistant Professor, Department of Mechanical Engineering, Smt. KashibaiNavale College of Engineering, Pune-41

Abstract:-HVAC system (commonly used in the air conditioners) is very efficient and reliable but it has some demerits. It has been observed during the last two decades that the O_3 layer is slowly destroyed because of the refrigerant (CFC and HFC) used for the refrigeration and air- conditioning purposes. So thermoelectric device is one of the best solutions to these problems.This review includes basics of thermoelectric cooler, its parameters and previous research on thermoelectric cooling considering different conditions such as transient super cooling and pulse current.

Keywords: Peltier Module, Peltier cooling, Cooling load ,Pulse operation, Multi-staging

I.INTRODUCTION

Thermoelectric phenomenon is an age-old concept, but due to various drawbacks such as cost, reliability etc. it has not been used in day todays life. Peltier Effect, Thompson effect and Seebeck effect is the base of thermoelectric phenomenon. Peltier effect was discovered 150 years i.e. on 1834 by Jean Peltier [7,9]. Recently thermoelectric effect has been developed simultaneously with two major fields Optoelectronic and Photonics. The Phenomenon is popularly used in Diode Lasers, Super Luminescent Diodes (SLD), Different Photograph Identifiers, Charged Coupled Devices (CCD) and more.

In thermoelectric cooler peltier effect is the backbone of the overall functioning. The entire thermoelectric concept is implemented in the cooling system using the Peltier module that has been described in the paper. The Peltier effect is basically the effect in which due to opposite polarity of potential difference across two different conductors, temperature gradient is created and it causes flow of heat from hot junction to cold junction which is used for cooling purposes [1-3].

The conventional Heating, Ventilation and Air Conditioning(HVAC) system has multiple demerits which is hazardous to human beings and harmful to the Earth's environment. The conventional systems use harmful refrigerants like ammonia and greenhouse gases like Chloro Fluoro Carbons(CFCs) and Hydro Fluoro Carbons(HFC's) which when released by these system react with the ozone (O3) layer and cause global warming.[1,3,7]

All these gases lead to global warming as when they reach the ozone layer, they decompose in presence of sunlight to release chlorine which reacts with ozone to deplete it.In such a manner, there are holes formed in the ozone layer due to which UV rays from sun enter our atmosphere,cause rise in average temperature of the earth and cause harm to the skin, even leading to skin cancer [1,3,7].

Therefore, taking these demerits into serious consideration, future generations have to strictly abandon the use of conventional HVAC system and shift to Thermoelectric cooling technology. In thermoelectric cooling, the peltier module is used which uses green technology.

II.Peltier Module

Basic module of TEC’s as shown in fig.1. mainly consists of two N & P type semiconductors, which are arranged thermally in parallel and electrically in series. These semiconductors are placed within two ceramic plates.

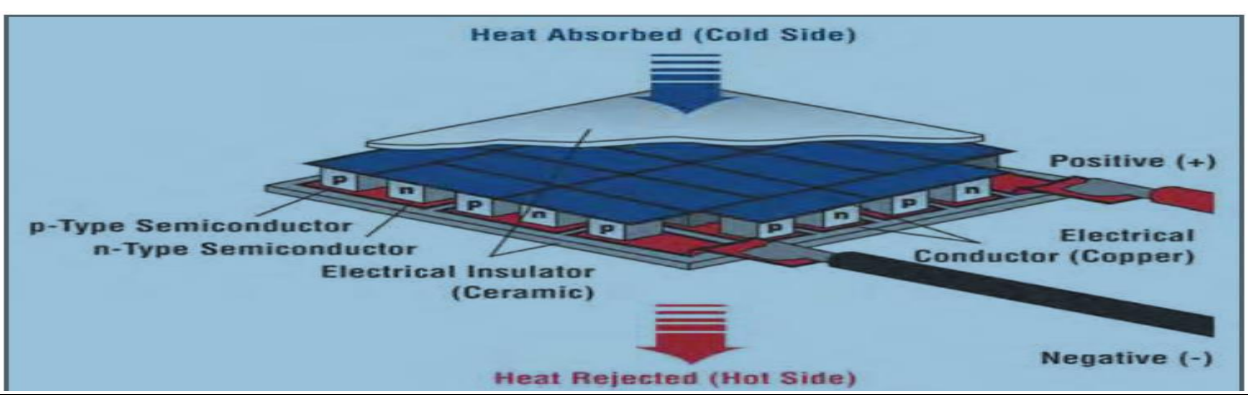

Fig.1. Construction of Thermoelectric Module[3]

In actual working, when voltage applied to free ends of semiconductors; electron flows either from P to N or N to P depending upon heating or cooling condition. When electron moves from Pto N type material, electron absorbs thermal energy reaching to the higher energy state.(As shown in fig.2) Continuing to these, when electron flows from N to P, electron jumps to the lower energy state by releasing thermal energy.

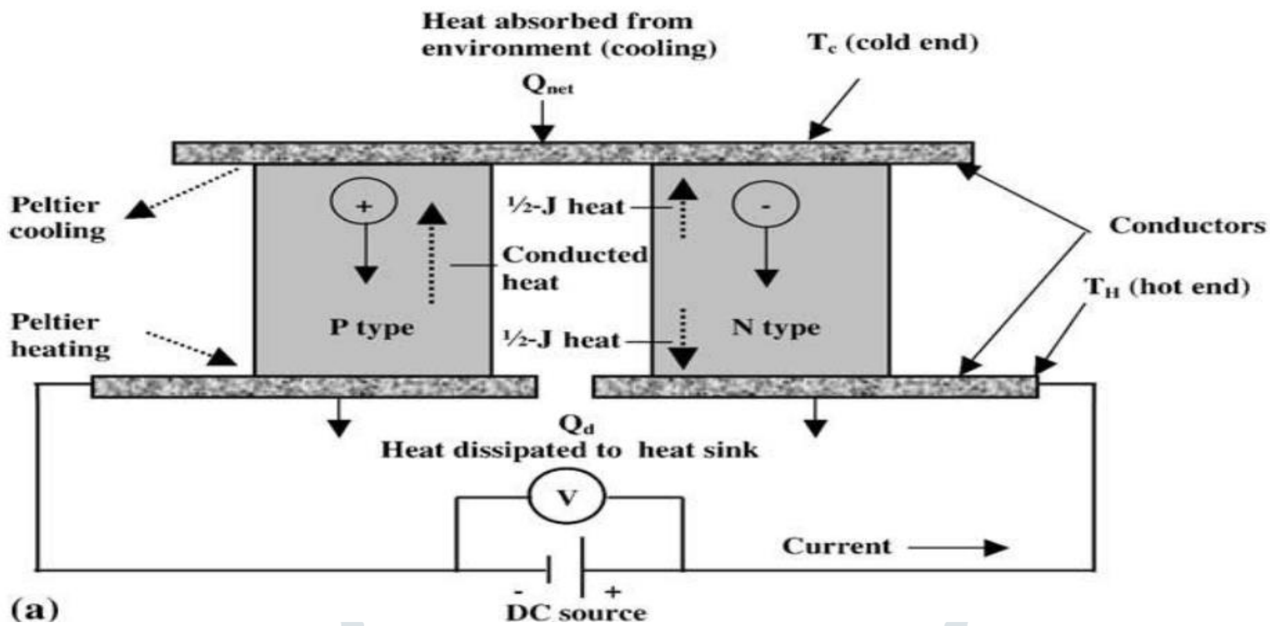

Fig.2.Working of thermoelectric module [1]

III.PARAMETER OF THERMOELECTRIC MODULE

While designing of thermoelectric cooler various factors of TEC module are taken into consideration. TEC modules can be distinguishon basis of shapes, sizes operating current, operating voltages and ranges of heat pumping capacity. Therefore a designer has to consider following parameters of module while designing TEC.

1.Cold side temperature (Tc): It is lowest temperature which is expected to achieve from a peltier module when current passed through it. Main aim of this parameter is to cooled down the air which when passed over heat sink attached to the cold side of peltier plate. Main factor to be consider is that the temperature of the plate should be lowered than the expected desired temperature of air.[1,3]

2.Hot side temperature (Th): The hot side temperature considers mainly two factors. A first one is consider as ambient temperature of air i.e. surrounding air and the other one depends on capacity of heat sink to transfer heat from TEC to air.[1.3]

3.Temperature difference (ΔT): It is difference between hot side and cold side temperature but actual temperature difference (ΔT) is different than system temperature difference.[1]

$$\Delta T = Th - Tc$$

4. Cooling load: In TEC's cooling load has a prominent place because everything boils down to the ability of TEC to either absorb or reject heat .Here cooling load (Qc) is calculated by product of mass flow rate of air (m) , specific heat of air (Cp) and temperature difference (ΔT).[1,3]

$$Qc = m\ Cp \Delta\ T$$

5. Thermoelectric Assembly-Heat Sink

Thermoelectric assembly consider prominent place in TEC's. AS it bridges gap between the TEC and the fluid to be cooled or heated.Without the heat sink TEC may get damaged.The actual and system temperature difference hugely rely on position and conductivity of heat sink.The thermal resistance of heat sink can manipulate ambient temperature and cooling load of TEC's.There are types of heat sinks [1];

1. 10 to 15 C for a forced air cooling system with fins- Forced convection

2. 20 to 40 C for cooling using free convection - Natural convection.

3. 2 to 5 C for cooling using liquid heat exchangers - Liquid cooled.

6.CoefficientOf Performance of TEC's :

The COP of TEC is the thermal efficiency of thermoelectric system. COP is the ratio of thermal output power to the electric power of TEC's [3].

Pe = Qh-Qc

COP = Qc/Pe, where Pe = Electrical Input power

Previous researches on Thermoelectric cooling:

1. Study of Peltier cooling via pulse current:

In modified pulse operation unlike normal pulse operation along with the pulse current,the hot side heat transfer coefficient is also pulsed. For the reason above numerical model of thermoelectric cooling system is developed by considering 1-D unsteady state heat transfer. For this purpose constant heat flux conditions and convective heat transfer conditions are consider at cold side and hot side respectively.Further various factors of TCS such as variable pulse current ratio, cooling load, variable pulse width etc. were studied [8]. With changing the operational scheme, it is possible to increase COP and cooling load by integrating thermal energy storage with modified pulse [6].Various results were obtained by considering above factors which included cooling power of 600 Watt, COP of 1.01 which are 23.23% and 2.12% higher than normal modes of operation respectively. Also brief study about different shapes of pulse brought to the conclusion that square or rectangular-shaped pulse gave higher cooling power and COP than ramp and exponential type of pulse [8]

As compared to single stage, two stage TEC with discrete pulse current gives a lower cold end temperature Tc min, and more drawn out holding time(δt) for super-cooling state. Due to transient super cooling, hot stage reduces hot end temperature of cold stage which enhances peltier cooling [10].

2.Performance of thermoelectric cooler under influence of thomson effect:

Thomson effect and ideal equation predict the performance.A detail of established fundamental conditions of thermoelectric cooler from the Thomson relationship to the non-differential conditions with Onsagar's corresponding are performed to study the Thomson effect related to perfect conditions. Thomson coefficient is assume to be zero in order to obtain ideal equation.The ideal equation effectively predicts the performances ofthermoelectric coolers if the Seebeck coefficient is correctly evaluated at the average temperature of the low and high junction temperatures.Positive Thomson effect slightly improves the performance while negative Thomson effect slight reduce the performance [9].

3.A numerical study on the performance of the thermoelectric module with different heat sink shapes :

In this paper a thorough study is conducted on various types of heat sinks. As a heat sink bridges the gap between TEC plates and air to be cooled or heated in TEC so itis very important to select a perfect type of heat sink depending on various factors such as material to be used, thermal conductivity of the material, shape of the heat sink etc.Here a TE module with heat sink was developed using CFD.The preliminary experimental simulations on the TEMs problem were conducted to validate the present numericalsimulation code. The variation in temperature of the sides of the TEMs over time was obtained from the experiments, and the results were compared with those of the CFD.ON the basis of temperature difference according to relation of the COP performance of TEM was evaluated.To study the effect of the various design parameters of theheat sink, the heat transfer process was analyzed. These parameters were classified according to conduction or convection effects. As a results, the various parameters of the heat sink have an influence on the performance of the TEM [11].

4.Multi-staging of thermoelectric cooler

In single-stage TEC, maximum coefficient of performance and heat flux is not attained. Apyramid type multi-stage TEC is designed using key parameters. It shows 10 no. of stages are required; which are determined by using the heat sink thermal resistance and achievable COP. Analytical formulas also derived giving relation between heat sink thermal resistance and overall COP with respect to variation electric current. The thermal resistance of hot side heat sink is predominant factor in the performance of TEC using multi-staging. Use of higher thermal resistance heat sink allowed when we increase no of stages. The optimal design can be achieved by considering overall COP and heat sink[5].

5. Recent development in thermoelectric cooler:

In this paper dimensional parameter ZT, along with physical properties such as electrical resistivity (σ), Seebeck coefficient (α) and the thermal conductivity (k) at absolute temperature T taken under a consideration to determine performance of TE material. Material with higher ZT is better to select. Bi-Te semiconductor couple has a highest ZT (about 2.4) at room temperature which gives theoretical COP just 3.97 at 313 K. As compared to conventional refrigerator , ZT must be larger than 3 in order to achieve larger COP .So it is quite important to find out material with higher ZT [7].

$$ZT=\frac{\alpha^2\sigma T}{k}$$

$$COP = \frac{TC}{TH - TC} \cdot \frac{\sqrt{1+ZT} - \frac{TH}{TC}}{\sqrt{1+ZT} + 1}$$

6.Thermoelectric Air Cooling For Cars

In this paper complete HVAC system in vehicle is planned to be replaced by TEC. Objective of the paper is to study the current HVAC systems and to find its con and try to replaceit with another sound technology. The project implemented a structured system analysis and design methodology approach to achieve the project objectives. A TEC module is designed with number of TEC plates sandwiched together. Then tests are carried out to study following aspects like cold side temperature, hot side temperature, temperaturedifference, heat absorbed,etc. After the test a conclusion was obtained that a temperature difference of 7 degree Celsius was obtained. The temperature of air was reached upto25.8 from 32. But this technology is inefficient at a temperature of ambient air at 40 and plus.But with better cold sinks, good quality of TEC plates desired goals of replacingHVAC system can be achieved. Also with slight changes this TEC can also be used as a heater in cold regions [3]

References:

1.Prof. N. B. Totala1, Prof. V. P. Desai, Rahul K. N. Singh, DebarshiGangopadhyay , Mohd. Salman Mohd. Yaqub, Nikhil Sharad, Study and Fabrication of Thermoelectric Air Cooling and Heating System,International Journal of Engineering Inventions (2013) 20-25.

2.Jatin Patel, MatikPatel,Jigar Patel, HimanshuModi,Improvement In The COP Of Thermoelectric Cooler, International Journal Of Scientific & Technology Research Volume 5, Issue 05, May 2016

3. Manoj S. Raut, P. V. Walke, Thermoelectric air cooling for car, International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA) 2012.

4.Tung T. Lam, Sidney W.K. Yuan, Ed Fong, William D. Fischer,Analytical study of transient performance of thermoelectric coolers considering the Thomson effect,International Journal of Thermal Sciences 130 (2018) 435–448.

5.G. Karimi , J.R. Culham , V. Kazerouni ,Performance Analysis of multi-stage thermoelectric coolers. November ,International journal of Refrigeration 34(2011) 129-135.

6.Tan G, Zhao D. Study of a thermoelectric space cooling system integrated with phase change material. ApplThermEng 2015;5(86):187–98.

7.Wei He,Gan Zhang, Xinxiang Zhang, JieJi, Guiqiang Li, Xudong Zhao, Recent development and application of thermoelectric generator and cooler,Applied Energy 143 (2015) 1–25.

8.S. Manikandan, S. C. Kaushik, Ronggui Yang, Modified pulse operation of thermoelectric coolers for building cooling applications,Energy Conversion and Management 140 (2017) 145–156.

9.HoSungLee ,The Thomson effect and the ideal equation on thermoelectric coolers,Energy 56 (2013) 61-69.

10. Yan-Wei Gao, HaoLva, Xiao-Dong Wanga, Wei-Mon Yanc, Enhanced Peltier cooling of two-stage thermoelectric cooler via pulse currents,International Journal of Heat and Mass Transfer 114 (2017) 656–663.

11. Young Min Seo, Man Yeong Ha, Seong Hyun Park ,GeunHyung Lee , Young Soo Kim c, Yong Gap Park, A numerical study on the performance of the thermoelectric module with different heat sink shapes, Applied Thermal Engineering 128 (2018) 1082–1094.