Review on Cooling and Power Generation by using Thermoeletric Module

Amit Gundale, Amol Ganje, Vishal Beldar, Prof.Sumit Dubal
Mechanical department, Mechanical department, Mechanical department, Mechanical department, Pune University, Pune University, Pune University, Pune University

Abstract— **The present cooling and power generation systems use non renewable resources causing its depletion and pollution which is harmful to nature as well as humans, To overcome these problems peltier module is used which is eco- friendly and compact which current society requires ,but due to its low efficiency several improvements are carried out causing everyone's attention as an alternative for conventional sources. By using different materials exibiting thermoelectric properties like electrical and thermal, efficient modules are fabricated .By changing parameters like figure of merit(zt),geometry of legs, contact surface and load resistance performance have improved.**

Keywords— **Thermoeletric effect, semiconductors, waste heat management, power generation.**

I. INTRODUCTION

Nowadays demand for Conventional energy has been tremendously increased therefore it essential to use alternate sources for energy generation. By considering this fact we searched for alternate energy sources. On other hand Cooling systems used cause problems like pollution, noise and global warming so to avoid these thermoelectric devices can be used for cooling, heating and also for power generation purpose, it has its application in various industries and fields.

The common refrigerant used is HFC which are leaked and slowly ascend into atmosphere A single molecule of HFc can destroy thousands of O_3 molecule. These HFCs once destroy O_3 layer it takes hundreds of years to recover its thickness as it is formed by intricate reactions. This is because as HFCs comes in environment, they remain in atmosphere several years. The capacity of HFCs to increase in earth temperature 10% is contributed by HFC's only. That leads to the emergence of finding an alternative for conventional HVAC system, i.e. thermoelectric system(cooling and heating) [9].

Direct conversion of temperature differences into electric voltage is known as thermoelectric effect. Voltage is created by thermoelectric device when there is a temperature difference on either side. On contrary, when a voltage is applied to it, it creates a temperature difference. The term "thermoelectric effect" encompasses three effects: Seebeck effect, Peltier effect, Thomson effect.

There are many advantages of Thermoeletric Peltiers like reliability, Compactness, easy use, Lightweight, Fast thermal response, noiseless, no mechanical movement and eco friendly though main problem faced by using peltier is that its performance is low, there have been recent developments for increasing its performance .Couple is term used in most modules as even number of P-type and N-type dice and one of each sharing an electrical interconnection. While both P-type and N-type materials are alloys of Bismuth and Tellurium, both have different free electron densities at the same temperature. Deficiency of electrons is in P-type, while N-type has an excess of electrons. The current considers P type material as a hot junction which is needed to be cooled while N-type as a cold junction needed to be heated. The direction of the current will determine if a particular side will cool down or heat up. In short reversing the polarity will switch the hot and cold sides [2]. Thermoeletric elements electrically connected in series using copper electrodes and thermally in parallel. Such configuration is called the "Peltier Thermopile". [23] Every peltier module can withstand certain temperature [5]. Performance improvement methods of thermoelectric module (TEM) can be classified into two main parts. The first part is related to the materials by which the n/p type conductors of thermoelectric are made. All other effective parameters including heat sinks, flow and thermodynamic conditions etc. are arranged in the second part [4] Organic polymer /inorganic thermoelectric composites are emerging green energy materials for diverse applications including harvesting waste or low quality heat, local cooling sensing and wearable electronics. TE performance is increase by inorganic nanoparticles (PEDOT:PSS)SnS nanobelt [6].

A. Peltier for Cooling effect

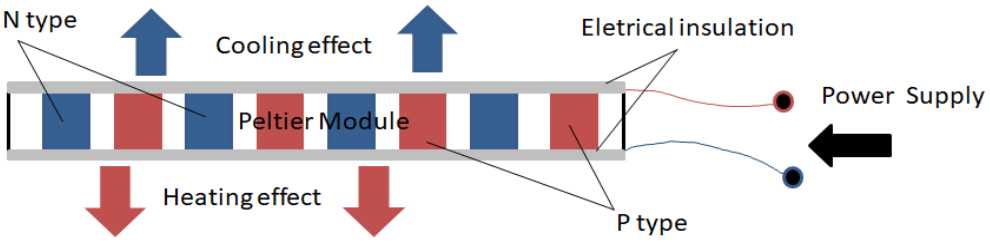

Fig 1-Cooling and Heating using power input in TE module

In any mechanical system to obtain maximum efficiency optimum temperature is required to maintained, so cooling is essential for optimal performance of system. For cooling heat exchangers, radiators, intercoolers, coolant, cooling towers, heat sink and vortex tubes are used. Conventional Refrigeration consume enormous energy and used chloroflurocarbons which can cause ozone depletion. Their are various devices for cooling while technology advances Thermo electrics are being advantageous .Prof Rajendra P patil et.al reviews the developments in TER system over the years. Their study on the thermoelectric refrigeration emphasize that the TER system is a novel refrigeration system which will be a better alternative for conventional refrigeration system. [2]. Cooling capacity and COP is inverse.

Military and medical Field

In military and medical science field refrigerators are used to cool samples it also include refrigeration units for storing blood and other specimens[2]. Cooling is needed in medical field for small as well as large causes for pain.For reducing pain and swelling, cooling wraps for dental inflammation and large causes like horse tissue therapy. For cooling Purpose ice is used which is to be prepared and stored which requires storage facility and high energy consumption. Cooling of living tissue is achieved by peltier module [1]. As Efficiency of thermoelectric cooling increases it provides various benefits can be used in ambulance for portable refrigeration for storing medical equipments, blood and antibiotics. Blood plasma is manufactured using freeze drying.. Dead bodies can preserved at -70^{o}C for few days[3].

Avoinic and Railways

Fuel Consumption of diesel electric generator can be reduced by using thermoelectric generators. The results indicate that an increase of the electric power density is possible [7].For the avionic processor cooling application, the optimized thermoelectric cooling system is able thermally stabilize without over sizing the heat sink. The optimized thermoelectric system is able to cool down automotive A/C application. Tristan Caroff et.al explained thermal resistance of the Peltier coolers [11].

Other Applications

Solar Power is one of the best alternative for non renewable fuels, Solar refrigeration has become alternative technology for refrigeration by using solar power with peltier module[3]. Compressor based cooling is not economical for electrical cars and thermal performance so they increase production cost and decrease the quality of automobiles, hence they consider thermoelectric as promising method for air cooling process for such a cars[4]. TEC was more sensitive to external fan speed or liquid velocity than purely air cooling or liquid cooling. Micro TEC are used in LED to reduce junction temperature and improve its life cycle. Models of LED are established and solved in Comsol Multiphysics [24]. Artificial neural network can be self trained with IR camera images in order to control the temperature of micro fluidic reactor with high speed and accuracy.IR camera has various advantages over thermocouples and conventional PID for less overshoot and faster settling time [29].

B. Power Generation

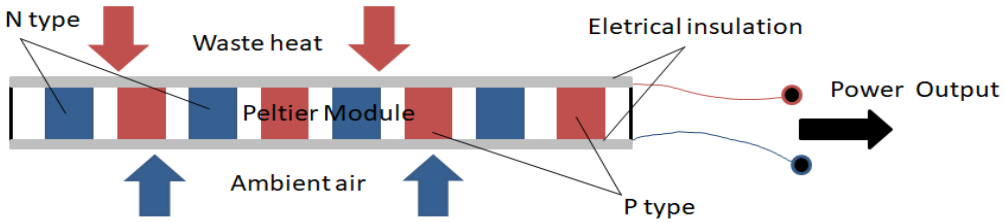

Fig 2-Power generation in TE module

To operate any automobile or other equipment their is need of power so it is great challenge to us to generate power .Their are different ways to generate power by using diesel ,Petrol, gasoline and Coal from this we get large amount of power but this energy sources have some demerits. Waste heat from automobile exhaust, industrial waste gases, hot air is free source for power generation. Heat exchanger is used to transfer heat from fluid to TEG, electric current will be produced by placing heat sink to cold side by exposing it to atmosphere [23].

Two ways of harvesting energy are direct sunlight using Fresnel lens during daytime and one from simple heat source candle during night time which is enough to light LED and charging of mobile phone [5]. Power is generated using waste heat of chimney , it can be concluded that at start of chimney and end it have high power output in which inlet position power obtained is maximum. Heat transfer on cold side of TEG has more influence than that of hot side. Cold side is exposed to outside air while hot side is exposed to exhaust of chimney.CFD modelling is performed for experiment while ANSYS Fluent is used for numerical solution and user defined function(UFD).Increasing one side velocity than other don't have much effect on output power [26].

1. Different Thermoeletric Generator

1.1 Solar Thermoelectric Generators (STEGs)

Solar Thermoelectric Generators (STEGs) is one of the most important technology for solar energy conversion. A high performance STEG system combined with solar concentrator and carbon nanotubes(CNT)absorber which can greatly improve the

solar thermal conversion process. Properties of CNT film directly affect performance of solar absorber. Glass cap below Fresnel lens is to reduce convective and radiation heat losses. With an increase of solar concentration power output and open circuit voltage of STEG were increased however further increase in solar concentration would affect performance of Bi_2Te_3 TE and result in large radiation loss, to improve the system efficiency of STEGs is to directly improve the ZT value of material either by nano structured fabrication or seeking new thermoelectric materials with record high ZT value. Carbon nanotubes as solar absorber on hot side giving temperature difference of 240°c and max temp on hot side 600°C . temp difference increased by 12 - 67%.CNT film was characterized using scanning electron microscopy(SEM)[25].

1.2 Off diagonal thermoelectric generator

Density based topology optimization method is suitable to optimize off diagonal thermoelectric generator figure of merit by 233% and electrical power output by 229% as compared to other optimization methods. Optimization is by determining optimal tilting angle and volume fraction between two active materials placed in layer configuration. 3 issues are faced by topology optimization parasitic losses, manufacturing of model and temperature independent material parameters. Design should be based on end goal application. Length of TEG and impedance in outer electrical load are critical parameters. Off diagonal TEG are less prone to wear and thermo mechanical stresses. But diagonal TEG are better than off diagonal TEG [13].

1.3 Hybrid thermoelectric generator

To increase efficiency of thermoelectric composite material composed of Bi2Te3 nano wire matrix with homogenous dispersion of carbon nanotubes through in-situ synthesis to increase thermoelectric properties .in-situ is better process than ex-situ for better results. As the percentage of carbon nanotube increase seebeck coefficient and ZT will increase. Seebeck coefficient and electrical conductivity improved through annealing and mechanical pressing. Crystal structured and phase was characterized by XRD. surface morphology was analyzed by SEM [22]. Hybrid system made up of TEG and concentrator photovoltaic technology(CPV) with nanofluid as cooling element. System with glass cover having high ZT value and concentration will be competitive. Passive cooling is used as it has less cost and is less complex. TE materials with high ZT value would improve heat recovery and efficiency. It consist of single junction a-Si and hetero junction Cu_2ZnSnS_4.temperature and concentration ratio are parameters in CPV-TEG [28].

C. Development In Thermoeletric Peltier

a. Development

Using hybrid systems like Vapour compression system with thermoelectric system for better temperature control and high COP[2]. Peltier module is used with control system for maintaining required temperature is achieved by pulse width modulation(PWM) by Proportional integral derivative (PID) controller [1].Hamed Sadighi Dizaji et.al studied Peltier air cooler ,they developed peltier to experimentally clarify the effects of DC voltage, electrical current, air inlet temperature, air flow rate, water inlet temperature and water flow rate on exergetic characteristics of thermoelectric air cooler [4]. It is portable and economical system [3]. The use of quantum well structures and thin films is the current research efforts for thermoelectric devices in order to increase the performance of thermoelectric devices. Alternating layers of Sb_2Te_3 and Bi_2Te_3 are used to make thin films used in thermoelectric coolers. The use of thermo electrical wires in the nanometer scale grown inside of a nano porous aluminum matrix is used in order to improve electrical and thermal parameters beyond bulk materials. Structures like alternating layers(thin) of quantum wells are used, which improves the electrical and thermal parameters . The FOM of merit of thermoelectric cooler and the efficiency of thermoelectric devices not only depend on material parameters and temperature difference, but also on the absolute average temperature the device operates in, making different materials suitable for different operating temperatures [10] ,optimised topology. Both p type and n type are cubic [23]. MATLAB is used to evaluate mathematical model .Decrease in Fill factors (FF) enhances increment of power factor(PF).Lower ff means less amount of TE materials to build TE module, lower cost. TE material is costliest factor in modules. PF should not be disregarded against ZT. Oxides and skutterudites have better performance in TE materials by nano structuring and doping [27]. Nano TEG module are fabricated by regular micro electronic fabrication process. The optimization of nano TEGs performance will increase power harvested significantly. The sales of nano TEGs are assembled in such a way (series and parallel)that total electrical impedance can be significantly reduced if needed. Higher see beck coefficient can be obtained by optimizing array of membranes and geometry for high generation of power [21].

b. Strength

Stress can be reduced by Certain opening angles of n type and p type legs. Mechanical stability is achieved by superposing original channel. Honey combs rings were considered on both side for best results. Increase in power density can be obtained by optimizing TEG which can be done by increasing heat transfer coefficient of heat exchanger[7]. Flexible and double bondable Bi2Te3 based module is introduced and optimized with regard to the power density and mechanical strength. It is integrated into waste heat exchanger for power output Performance can be increased by certain changes in system design [7].

c. Porosity

The addition of pores is proposed as one way for resolving limited heat transfer between thermoelectric modules and external heat reservoirs reduces temperature difference imposed on thermoelectric materials ,microscopic pores in thermoelectric material reduces the power output of thermoelectric generators. By keeping lower thermal conductance of the module, the temperature difference between two ends can be increased, resulting in improvements in the maximum power and the conversion

efficiency .The power and the conversion efficiency increase as we introduce more porosity. The lower thermal conductance of the module with porous elements allows the decrease of the thermal flux density between the ends of the thermoelectric module, and thus reduces burden of maintaining a high external heat flux [8].

d. Geometry

Coefficient of performance of TEG will be affected by leg length. Small cross section area of TE legs increases power density. Geometric model consist impacts like air zone, electrical contact resistance, thermal contact resistance. TE module optimization is based on hill climbing algorithm and is applied for maximum output [29]. 3D numerical simulations have been performed for the optimization of design. Input current leg geometry and contact layer have been optimized which gave operational reliability and max cooling performance, as leg height increase the cooling capacity of TEC continuously decreased and cop lowers. Smaller leg height has superior cooling performance .The temperature gradient in p type leg was always higher than that of n type leg. temp gradient in leg and contact layers decrease significantly with the increase of leg cross sectional area and operational reliability increases. Numerical simulation are performed using ANSYS Multiphysics 15[16]. By varying leg size and dimensions figure of merit(ZT),see beck coefficient ,internal resistance and power output [17].

e. Materials

Thermoeletric module has widely used for waste heat management. Thermoeletric elements are made of bulk alloys materials like Bi_2Te_3,PbTe,SiGe,$CoSb_3$ among which Bi_2Te_3 is most popular high ZT around 1 and cost effective [23]. N type Mg_3Sb_2 based Te material have high ZT, non toxic and low cost, its conversion efficiency of single leg is 10.6% at 400°c temp difference. It is mid temperature n type TE material. It fabricated using hot press to achieve good bonding strength and low electrical contact resistance. Contact was observed in SEM and energy dispersive X-ray Spectroscopy(EDX) show no diffusion from contact layers to TE [14]. Introduction of indium in $Zn_{13}Sb_{10}$ for reduction in Zn its deficiency is supported by X ray powder diffraction EDS elemental analysis. Good thermoelectric material can be described as phonon glass electron crystal, it posses low thermal conductivity of phonon glass and low electrical resistivity of electron crystal. Ideal dopant for $Zn_{13}Sb_{10}$ would be an element which keeps thermal conductivity suppred and power factor to increase. $Zn_{13}In_xSb_{10}$ need no extra Zn while its also suggest it can be optimized to increase power factor of Zn13Sb10 based materials [15]. Speak plasma sintering (SPS)with melt spinning technique is used to synthesize P type nano structured $Si_{80}Ge_{20}$ alloy. Tuning electrical properties using different dopants like P, B, Na<Sb , InSb and Gap. Melt spinning with SPs is compared with ball milling and SPS which resulted in MS+SPS produce higher semiconducting behavior. It increased ZT around 46% at room temperature while reducing time for preparation for manufacturing for commercial use. Decrease in thermal conductivity also increased see beck coefficient [18]. Binary skutterudites are one of the promising TE compounds. Sb doping in $Co_4Ge_6Te_6$, spark plasma sintering to manufacture specimens in short time for high performance. Mica flims are used for electrical insulation for high quality of yield.sb doped samples demonstrate highest power factors were achieved for $Co_4Ge_6Te_6$ based compounds till now [19].

.

II. Conclusions

This paper focuses on use of peltier device in various applications like power generation and cooling. Thermal and electrical parameters are optimized by using different materials as n-type and p-type semiconductors. Various fields in which cooling and power is required use of peltier is introduced due to its several advantages. In medical, military and automobile industries use of peltier is boosted ,while its other use like power generation is also used in various applications like avionic, railways and automobile industry. It also gives idea about waste heat management which can be cultivated for future use to increase efficiency of system.

Acknowledgment

The author would like to thank Mr Sumit Dubal for his valuable guidance during the preparation of review paper .The author would also like to thank all the peoples who have helped directly or indirectly for preparation of this paper.

References

[1] Zdenek Slanina,Martin Uhlik,Vaclav Sladecek,Cooling Device with Peltier Element for Medical Applications,IFAC PapersOnline 51-6(2018)54-59

[2] Prof.Rajendra.P.Patil,Pradhyumna Suryawanshi,Akshay Pawar,Avdhoot Pawar,THERMOELETRIC REFRIGERATION USING PELTIER EFFECT,IJESRT 6(5):May,2017

[3] Oshin Dhage,Rupali Gaikwad,Pooja Nagrale,Pooja Bomratwar,Anuradha Mogare,Solar Refrigeration System by using Peltier Module,International Conference on Recent Trends in Engineering Science and Technology(ICRTEST 2017),Volume 5 Issue 1 21-22 January 2017

[4] Hamed Sadighi Dizaji,Samad Jafarmadar,Shahram Khalilarya,Samira Pourhedayat,A comprehensive exergy analysis of a prototype Peltier air cooler;experimental investigation,Elsevier journal,Renewable Energy 131(2019)308-317

[5] N K Kaphungkui,Anku Phukan,Manash Sharma,Abhishaek Gogoi,Masoom Subhani,Highly efficient electricity generation with Peltier Module,International Journal of engineering Treands Technology Volume 35 Number 10 May 2016

[6] Xuejiang Cheng,Lei Wang,Xin WANG,Gaunming Chen,Flexible films of poly(3,4-ethylenedioxythiophene):Poly(styrenesulfonate)/SnS nanobelt thermoelectric composites,Elsevier Journal,Composites science and technology xxx(2017)1-5

[7] Alexander Heghmanns,Michael Beitelschmidt,Sebastian Wilbrecht,Karlheinz Geradts,Gerhard span,Development and optimization of a TEG-system for the waste heat usage in railways vehicles,12th European Conference on THermoeletrics,Elsevier Journal,Materials Today:Proceedings 2(2015)780-789

[8] Anne Flora Ngwa Ngondi,Hohyun Lee,Daehyun Wee,Technical and economic analysis of thermoelectric modules with macroporous thermoelectric elements,Elsevier Journal,Energy Conversion and management 135(2017)327-335
[9] Prof. N. B. Totala1, Prof. V. P. Desai2, Rahul K. N. Singh3, Debarshi Gangopadhyay4, Mohd. Salman Mohd. Yaqub5, Nikhil Sharad Jane6, Study and Fabrication of Thermoelectric Air Cooling and Heating System, International Journal of Engineering Inventions, e-ISSN: 2278-7461, p-ISSN: 2319-6491 Volume 4, Issue 2 (August 2014) PP: 20-30
[10] Prof.Dr.Yehea Ismail,Ahmed Al-Askalany,Cooling and power generation,Thermoeletric devices,Center on Nanoeletronics and devices,2015
[11] Tristan CAROFF,Claude SARNO,Romain HODOT,Mauro BRIGNONE,Julia SIMON,New optimization strategy of thermoelectric coolers applied to automotive and avionic applications,Elsevier ,Materials today:Proceedings 2(2015)751-760
[12] Yeongseok kim, cheomlin shin,taesung kim,sang-woo kang,inhomogenity in thermoeectrics caused by peltier effect induced temperature gradient during spark plasma sinteringscripta materialia 158(2019)46-49
[13] Christian lungaard,ole sigmund,design of segmented off-diagonal thermoelectric generators using topology optimization,applied energy 236(2019)950-960
[14] Qing zhu,shawei song,Hangtian zhu,Zhifeng Ren,Realising high efficiency conversion of Mg3Sb2-based thermoelectric materials, journal of power sources 414 (2019)393-400
[15] Chun wan timuthy Lo,Taras kolodiaznyi,Yurji mozharivskyz,incorporation of indium into the Zn13Sb10 thermoelectric material,journal of alloys and compounds 780 (2019)334-340
[16] Tingrui gong, Lei gao,Yongjia wu,Long zhang,numerical simulation on a compact thermoelectric cooler for the optimized design,applied thermal enggineering 146 (2019)815-825
[17] R. ,errein,J.lynn,Mc sweeney,Thermal cycling of thermoelectric generator :the effect of heating rate ,applied energy 237(2019)671-681
[18] Riya thomas,ashok rao,nagendra s. chauhan,Melt spinning :A rapid and cost effect approach over ball miling for the production of nanostructrured p-type Si80Ge20 with enhanced thermoelectric properties,journal of alloys annd compunds 781 (2019)344-350
[19] Mousad Aminzare,Yu-chih Tseng,Effect of spark plasma sintering and Sb doping on the thermoelctric properties of Co4Ge6Te6 skutterudite, journal of solid state chemistry 269 (2019)434-441
[20] Hailong he Yi,wu,Weiwei Lui,mingzhe rong,comprehencic modeling for geometric optimization of a thermoelectric genertaor module,energy conversion and management 183 (2019) 645-669
[21] Dimitri tainaf,Anais prodhoum,Celiuen tTur,Theiry Crozzes ,Sebstein Dufresnes,Network of thermoelectric nanogenerataors for low poer energy harvesting, nano energy 57 (2019)804-810
[22] Hyeunhwan AN, mathew pusko,Dongwon Chun,Sanghyun park ,In-situ synthesis of flexible hybride composite films for imoproved thermoelectric performance ,chemical energy journal357 (2019) 547-558
[23] Ding Luo,Rounchen Wang ,Wei Yu,performance evaluation of a novel thermoelectric module wirth BiSbteSe based material , applied ennergy 238 1299-1311
[24] Dongfan Sung ,Guanyu liu,Limei Shen,Haunxin chen,Yu Yao,Modeling of high power light emiting diode package integrated with micro thermoelectric cooler under various interfecials and size effects ,energy conversion and management 179 (2019)81-90
[25] Long Li,Xiang Gao,Guang Zhang,Fufu Wang ,combined solar concentration and carbon nantotube absorber for high performance solar thermoelectric generators,energy conversion and management,183 (2019)109-115
[26] Aymen Eldesoukey,Hmdy Hassan,3d model of thermoelectic generator case study :effect of flow regime on the TEG performance ,energy conversion and management 180 (2019) 231-239
[27] Meysam karami Rad,aleriza Rezinia,Mahmoud Omid,Study on material properties effect for maximization of thermoelectric power generation,Renewable energy 138 (2019) 236-242
[28] P.M.Rodrigo,A.valera,Performance and economics limits of passively cooled hybrid thermoelectric generator-concentrated photovoltaic modules ,applied energy 238 (2019)1150-1162
[29] BenjaminA.Rezkin,karinaPopovich,Ryan L.Hartman,Artificialsneural network control of thermoelectrically-cooled microfluidics using computer vision based on IR thermography,computers and chemical engineering 121 (2019)584-593