iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** V **Month of publication:** May 2018

DOI: http://doi.org/10.22214/ijraset.2018.5325

Applications of Thermoelectric Energy: A Review

Shyam Patidar[1]
[1]Department of Mechanical Engineering (SVITS), Shri Vaishnav Vidyapeeth Vishwavidylaya, Indore (M.P.)

Abstract: Concept of thermoelectric (TE) energy makes it unique because of reversible energy conversion, e.g. from thermal to electrical and vice-versa. Seebeck and Peltier effects are base of all TE energy applications. Thermoelectricity has wide range of applications due to reversible energy conversion. In recent years, with technology development and global warming issues TE devices come into use in various applications because of its eco-friendly feature and distinct advantages. The thermoelectric energy has a vast range of applications in various fields like; electricity generation, refrigeration, air conditioning, particular heating/cooling, biomedical devices etc. due to its simple construction and mechanism, portability, require DC supply to run etc. This research paper thoroughly reviews the recent development and research work carried out by many researchers on thermoelectric energy applications in areas such as; power generation, refrigeration, electronic device cooling, automobile air conditioning & systems cooling, air cooling, medical field applications etc.
Keywords: Thermoelectric, thermoelectric energy, application of thermoelectric, thermoelectric cooling, thermoelectric refrigerator, thermoelectric generator

I. INTRODUCTION

World's energy demand is continuously increasing day by day and convention source of energy have limited stock. Also, conventional sources of energy have many issues of carbon emission; it is main cause of global warming. The thermoelectric (TE) system is quite suitable due to its renewable energy feature (means no carbon emission) and eco-friendly behaviour. Emissions of greenhouse gases are increasing globally because of continuous increase in demand of electricity, heating and cooling, refrigeration and air conditioning etc. Only green technologies such as wind power, solar power and other renewable energy sources can control the emission of greenhouse gases and play important role for sustainable development. Many countries are trying to control emission of carbon by forming new rules for industries. In recent few years, thermoelectric equipments have come out with potential as alternative eco-friendly applications. Applications of thermoelectric energy extended in various areas such cooling or heating, refrigeration, electricity generation, ventilation, air conditioning etc. due to its eco-friendly features and distinct advantages. Thermoelectric energy has potential to convert thermal energy into electrical energy and vice-versa. Due to solid state (no fluid/rotating part) mechanism of thermoelectric devices, it has variety of small applications for cooling of central processing units (CPU) and produce electricity in automobiles from waste heat [1].

II. THERMOELECTRIC PRINCIPLE

The transformation of temperature difference into electric current and vice-versa is called as the thermoelectric effect. The principle of thermoelectricity was discovered in 1823 by German scientist, Thomas Seebeck, he found that electric current continuously flow if close circuit of two dissimilar conductors formed and their joints kept at hot and cold junctions. The Peltier effect was discovered by French watchmaker, Jean Charles Athanase Peltier, Peltier use current as an interface among dissimilar conductor metals in circuit results, absorption of heat at one joint and release of heat at another joint; exactly reverse phenomenon of Seebeck effect. When current (I) flow from n to p type and electrons (e^-) pass from p to n type semiconductor materials; electrons jump from low energy level (p type) to higher energy level (n type) absorbs heat from the surrounding and vice-versa [2].

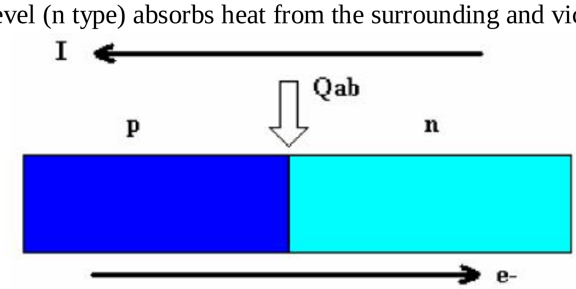

Fig. 1: Peltier Effect [2]

III. CONSTRUCTION AND WORKING PRINCIPLE OF THERMOELECTRIC MODULE

Thermoelectric module (TEM) is constructed by two unique semiconductor materials most commonly Bismuth Telluride (Bi_2Te_3) (one *n*-type and one *p*-type) used; because, they must have dissimilar electron densities. These two *p*-type and *n*-type (Bismuth Telluride) semiconductor dices are linked, electrically in series and thermally in parallel and sandwiched between the ceramics plates (electrical insulator). The *p*-type and *n*-type semiconductor dices are connected by copper tabs for flow of electricity. When input is given at free ends of two semiconductors, temperature difference generates across the junctions of semiconductors due to current flow. One side of junctions is known as cold side (heat absorbed) and other side of junctions is called hot side (heat rejected) [3]-[4].

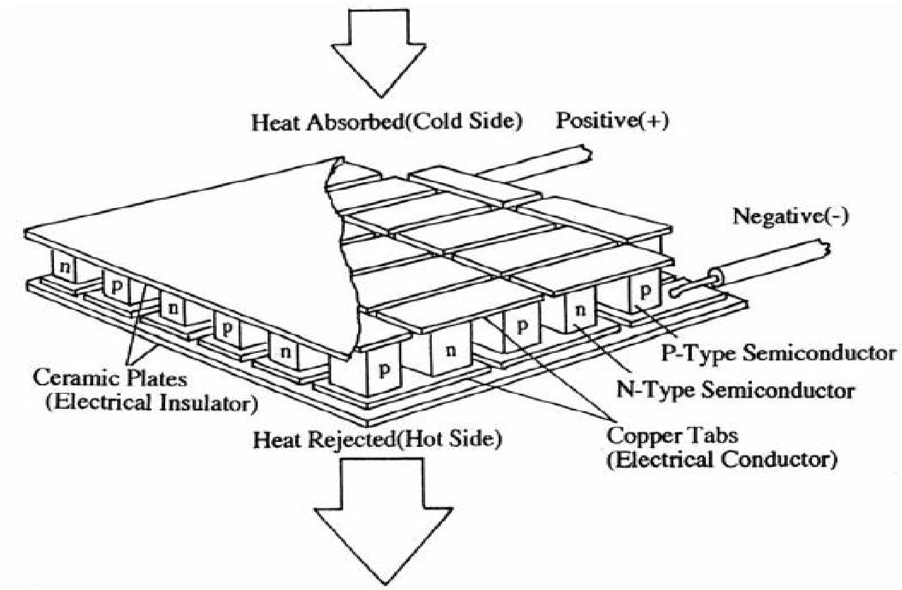

Fig. 2: Construction and Working Principle of Thermoelectric Module [3]

IV. APPLICATIONS OF THERMOELECTRIC ENERGY

The thermoelectric principles can be used to produce cooling or heating and power generation. Using the Seebeck principle; power can be generated by maintaining the two junctions of dissimilar conductors at hot point and cold point. Reverse of Seebeck effect is known as Peltier effect and Peltier effect produces heating or cooling. Using the Peltier module as heat pump/cooler the COP/efficiency of existing systems can be increase upto some extend. Figure 3 shows the cooling/heating and power generation phenomenon of Peltier and Seebeck effect respectively.

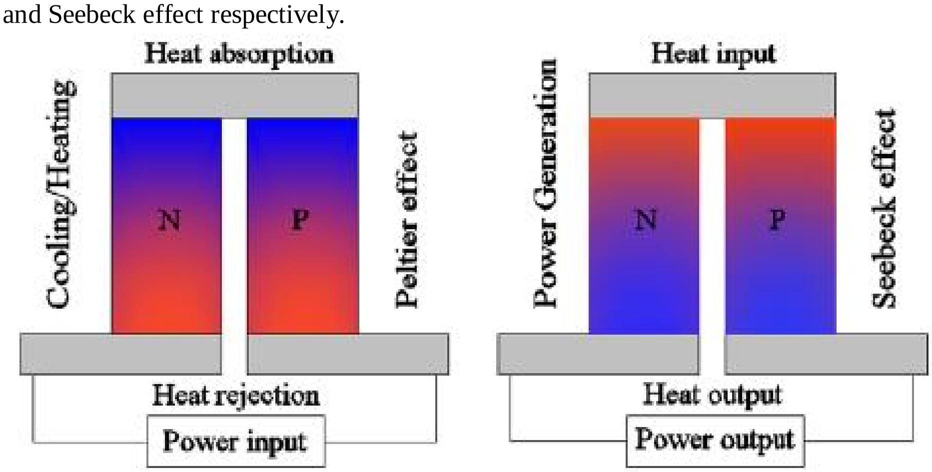

Fig. 3: Cooling & Heating and Power Generation [5]

TE has potential to convert temperature difference (thermal energy) directly into electrical power without any moving parts/mechanism. Using the waste heat energy can be converted into useful electrical power; that is used in automobiles to enhance fuel efficiency, power plants for waste heat recovery etc. Also, it has capability to convert electrical energy into cooling or heating purpose; that is using for automobile cooling, CPU's cooling, medical freezers etc. Various applications of TE energy has discussed below.

A. Thermoelectric Generators

Thermoelectric generator (TEG) is also known as Seebeck generator, that converts heat energy (temperature difference) into electrical power directly withought having any rotating part/mechanism. Jangonda et al. [3] reported the applications of TEG for power plant for waste heat recovery, automobiles TEG to increase fuel efficiency etc. Zheng et al. [5] have reported many applications of TEG for automotives, aerospace, industrial, domestic and thin film. This TEG's generates electrical energy from waste heat energy from automotives, aerospace, industrial etc. Singh et al. [6] have reviewed about efficiency of TEG, solar TEG's fabrication and performance, design and performance of a solar heat pipe TEG, internal heat losses, effects of geometry, Electric power generation from solar pond using combination of thermo-siphon and thermoelectric modules etc. and concluded; that the TE is better for electricity generation than the solar technology but low efficiency of TEG is drawback.

B. Thermoelectric Refrigerator

Using Peltier module a particular space can be cooled/maintained at certain temperature. Nikam and Hole [7] reviewed the use of Peltier effect and discussed integrated use and direct use of Peltier effect for refrigeration purpose. Integrated use of Peltier effects with vapour compression refrigeration system (VCRS) is developed and found that the COP increased as compare to the simple VCRS [2]. Direct use Peltier effect is done for refrigeration by Astrain et al. [8] and Alaoui [9]. Venugopal et al. [10] proposed an economical TE refrigerator in their research and reported that TE cooling is effective technique for the spaces compact in size. Dai et.al [11] proposed feasibility of portable solar TE refrigeration system for outdoor use. Some researchers reported that the COP of two stage/multi stage TE modules is more than the single stage TE refrigerator [12]-[13]. Use of TE refrigerator/freezer for medical purpose such as preservation and transportation of vaccination, blood serum, biological products etc. and for many surgeries had been reported by researchers [3], [5], [14].

C. Electronic Devices Cooler

Many high power electronics devices such as microprocessors, power amplifiers etc. and computers used in server continuously run and provide service to customers; during the run, large amount of heat produced within in system and it must have to dissipate from the system to avoid hardware failure and malfunction. Thus, cooling is required to enhance performance and life of electronic devices [5]. Cooling of these electronic devices is difficult using the traditional cooling systems; because, they are not compact and have no space for their installation. TE coolers have many advantages over traditional cooling system such as compact in size, vibration free because no moving part, maintenance less, run using DC supply etc. Liu et al. [15] presented a mini thermoelectric cooler (TEC) coupled with a micro thermo-siphon cooling system for cooling of CPU. Zhou and Ju [16] presented a generalized theoretical model for optimization of TEC design and maximized COP & capacity of cooling. Sun et al. [17] designed and developed a TEC system integrated with gravity assistant heat pipe (GAHP) for electronic devices to improve heat dissipation form hot side of TE module and resulted that improvement in cooling capacity by 73.54% and reduction in electricity consumption by 42.20% to produce same amount of cooling of electronic device [17].

D. Automobile System's Cooling and Air Conditioning

In automobiles there are many systems/devices such engine, exhaust system, gear box, cooling system etc. produces heat during the run; this automotive waste heat can be recover by using the TEGs. Many multinational automobile companies like Renault, Honda, Ford etc. have developed their systems to recover exhaust heat using TEG [18]-[20]. Baatar and Kim developed a TEG waste heat recovery system for car to replace the conventional radiator [21]. Orr et al. summarized many systems used TEGs and heat pipes to car waste heat recovery [22]. Papkin et al. proposed a TEG, which generates electricity using waste heat of vehicle engine cooling system and concluded TEG, reduce fuel consumption by 3-5 % and produce electrical power 500-700 W by using 4-6% of heat energy of cooling system [23]. Many car manufacturing companies such as Hyundai, Jaguar, Range Rover, Toyota, GM etc. are using TE modules to heat/cool car seats [24]. Deshmukh et al. proposed a thermo-electric principle based air conditioning system for car and resulted temperature drop of 5-7˚C [25].

E. Other Applications

There are many several other applications of thermoelectricity and also, it has potential to further development because of its simplicity, compact in size, work on DC voltage, portability, no rotating element etc. Various medical applications of TE such wearable sensors for electroencephalography (EEG), electrocardiography (ECG), electromyography (EMG) etc, human implantable devices (like; cardiac pacemaker, cardiac defibrillator, neurological stimulator etc) are reported by Chen and Wright [26]. Application of thermoelectricity is possible as dehumidifier by connecting photovoltaic modules in array [3]. A hybrid (thermoelectricity and evaporative cooling) air cooler is fabricated and experimentally found that hybrid air cooler performance increased by 10% than simple evaporative air cooler [27].

V. CONCLUSION

The applications of thermoelectric energy are summarized through this research work. Due to uniqueness and simplicity of TE principle for reversible conversation of energy; from one form to another form makes it more and more useful for various applications. Also, it has good future scope because of environmental issues and technology advancement. The only drawback it has low efficiency its own but integrated use of thermoelectricity has capability to increase the performance of existed systems. TEGs can play a great role in the various fields such power plants, furnaces, electrical power houses etc. to generate electricity from waste heat recovery. There are many opportunities of direct and integrated use of TE for refrigeration, if module size increase or introduce phase change materials. Also, portable size refrigerator is proposed by researchers in their research. In electronic devices cooling and performance enhancement, TEC play very crucial role due to its compact size, working mechanism, run using DC supply etc. Principle of TE energy has variable applications for automobiles as discussed. In biomedical field, TE has very wide range applications such various sensors, equipment, surgery tools etc. A direct application of thermoelectricity is useful for small & medium purpose and has low efficiency. But, though technology/material development; efficiency may increase in future. Integration of TE with many existed systems play significant role to improve their performance.

VI. ACKNOWLEDGMENT

I am grateful to all the authorities of Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore (M.P.) for providing necessary facilities and thanks to my friends and colleagues for their valuable support and suggestions for this research work. I am especially thanks to my family members for their kind support and love for successful completion of this research work.

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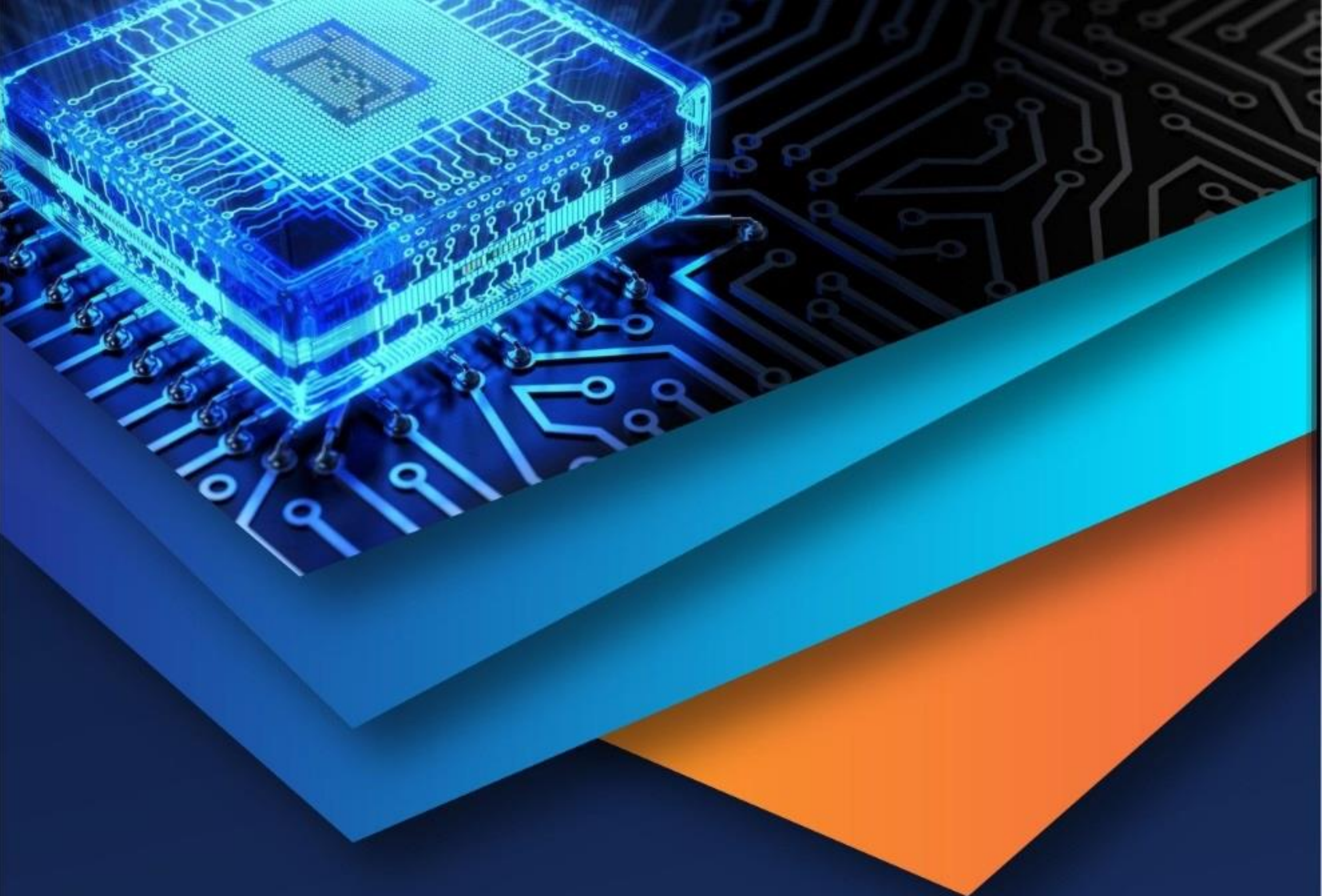

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