A review on thermoelectric cooling technology and its applications

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Abstract. Controlling devices thermally is an important issue to increase the span of any equipment that converts energy and nowadays available latest automation like LED, computer processors and electric battery. Thermoelectric Cooling Technology (TCT) is best option because it has high reliability and also its usage of energy is low for the cooling of devices, which are working on the basis of Peltier effect. TCT have features such as it is not big in size, very light in weight. Also it has no mechanical moving part which results in no or less noise, eco friendly and it does not has any working fluid. This paper presents a comprehensive review of TCT to understand the state of art in the cooling techniques and its applications on heat pipe cooling, sensible air cool warm fan and solar still productivity enhancements. The challenges and opportunities for future research are also highlighted.

1. Introduction

In nowadays, almost every day some new product is coming in market, there is also a need of thermal control for them. There are many examples of electronic products around us like even our fan, light, gaming consoles, diodes and other types of electronic gadgets. One of the possible ways to overcome the problem of thermal control is thermoelectric devices. The later have also been used in many types of industries, medical, space and terrestrial applications and are used in generating electricity. There are various cooling technologies that are used to maintain their temperature below the temperature where they are operated. Automatic industry has its own share of use which is thermal battery management system. There is also a need of converting of electrical power to thermal power. TECs help in the problem of current heat dissipation. There is always rapid development in thermoelectric materials. TEC’s which is also a cooling technique uses thermoelectric modules.

There are various advantages of these modules such as they are not dynamic, because no part of them moves, so they automatically become reliable. Also they are quiet appealing in many ways. They operate for a longer time and need less or no maintenance. Module has stack of TEUnicouples which are connected in series which also increases the severance and sustainability. They have complex applications. Peltier effect is the basis of the working of thermoelectric coolers. The former was discovered in 1834. In this temperature dissimilarity is created by flowing current across two different materials. It is one of three famous methods invented for thermoelectric cooling, the other one are
seebeck and Thomson effect. Where Peltier is based on junction phenomenon, the other two occur inside the materials.

There are various factors which decide the working of thermoelectric cooling like thermoelectric modules which are $\alpha, k$ and $\sigma$. $\alpha$ is regarded as seebeck coefficient, thermal conductivity is symbolised by $k$ and $\sigma$ represents electrical conductivity. $ZT$ is a dimensionless figure which is used to symbolise the influence of properties of materials on performance of thermoelectric system. That figure of merit is also defined as:

$$ZT = \frac{\sigma \alpha^2 T}{K}$$  \hspace{1cm} (1)

$$COP_{\text{max}} = \frac{T_c - \sqrt{1 + ZT - \frac{T_H}{T_c}}}{T_H - T_c \sqrt{1 + ZT + 1}}$$ \hspace{1cm} (2)

Where, $T_h$ is the hot side and $T_c$ is the cold side temperature of TEC. If $ZT$ increases then $COP_{\text{max}}$ will increase. Interest has to be increased in improvement of value of $ZT$ which is highly dependent on the need of well organised thermoelectric materials which are further used for refrigeration and generation of power. It should have high value of seebeck coefficient $\alpha$, increased amount of $\sigma$ and decreased level of $k$ for higher level of $ZT$.

| Method of Cooling | Parameters Dependency | Remarks | Reference |
|-------------------|-----------------------|---------|-----------|
| Thermoelectric assisted evaporative cooling | Contact resistance, Heat convection, TEG length | Important detailing for architecture for TEG-TEC system which is integrated. | Chen et al. [3] |
| Thermoelectric cooling temperature module coupled with density PCM | Specific heat | provide a compact light wearable cooling devices that help MS patients | Liet al [4] |
| solar thermoelectric cooling coupled with ventilation system | Voltage at which it is operated, temperature suitable for its working temperature | its typical applications like condensation of the risk coupling which is done with a PV system. | Lie et al [5] |
| thermo electric cooling module | Seebeck coefficient, Thermal resistance | Symbolising of TECT applied in electric cooling. | Luo et al [6] |
| Air duct aided with system which is photovoltaic in nature for cooling the space. | Photovoltaic panel and Thermoelectric module | optimum temperature difference, cooling capacity, COP, which also provides reliability and is free from Freon*. | Irshadet al [7] |

Also, common thermoelectric cooling system depends on limits like the current, thermal conductance present in extreme temperature sides of heat disposable area and temperature. Example is the
smallest shallow temperature of devices. Increase in power input results in development of presentation of cooling of electronic devices, which in return primes to higher consumption of power of cooler. Significant techniques have been applied to increase the performance of system and it decreases consumption of energy.

Liu et al.[2] deliberate a active model for composite systems as thermoelectric ventilator system to give warmth in winter and concurrently heat to attain inclusive use of solar radiations. Numerous researches have been done and are going on to smear the thermoelectric present in different types of cooling systems.In this paper we are going to present some precise claims of thermoelectric cooling technology like heat pipe cooling in more intricate facts. Sensible air cool warm fan is alteration of conservative fan system by the usage of thermoelectric module. Refrigeration system can be utilised in numerous fields. With assistance of coupling heat pipe the cooling performance of refrigeration system will get amplified.

2. Thermoelectric Cooling

This phenomenon was initially discovered by Alessandro Volta in 1794, in which difference in the temperature ranges resulted in thermo, electro and motive forces. 1821 resulted in Seebeck experimentally investigating a pattern and re-examined the Volta theory and later on in 1834 Peltier discovered the Peltier effect. This entire discovery helps in the quick expansion of thermoelectric technology.

2.1. Parametric Review

The physical conditions of materials are most important issues, validating the working of TCs, it is cumbersome to gain active, precise limits by experimental amount because of interaction between heat sink and TEC. Various researches are going on experimental size and simplification of limits of TCs which have been described in numerous publications if its physical conditions are confined to the logical model of TCs and could be solved by sequence of limitations. Typically, there are different procedures, like technique of thermal confrontation system and technique of number of transmission units, were applied on TCs for resolution of refining presentation. This cooler, from ages is commercialised for higher flow. One connection of which will be airconditioned and other when directly heated when current is passed through it. As a consequence thermoelectric cooler is a cooling technology by using thermoelectric unit.

2.2. Fabrication of Thermoelectric Module

The thermoelectric component encompasses numerous couples (p-n type) of portions, connectors which are metallic and insulating ceramic plates. The plates which are existing on both the sides of thermoelectric module acts as insulation in electrical appliances. Excess of electrons are present in n type semiconductor while p type has deficit of electrons. They together comprise a Unicouple. Inside thermoelectric module, these types of semiconductors are electrically joined in particular manner and also temperature wise they are arranged in parallel, which together comprise of numerous Unicouples. Electrons start moving from one type of semiconductor to another, the electrons jump from a higher energy state dissipating thermal energy. On going through, the lattice, the electron start moving through n-side to the p-side, that is to a lower energy level dissipating energy again in that case current flows from one type of element to another which is given below in figure 1.
2.3. Classification of Thermoelectric Cooling Technology

2.3.1. Active cooling in thermoelectric system (TAC). It utilises thermoelectric cooler to take away heat directly. In various cooling applications, TAC aids in preserving the devices at a condition of temperature which we need. As shown in figure 2, the specific system should be apprehended by giving it a TEC.

2.3.2. Self cooling in thermoelectric system (TSC). In this electricity is generated from generator from difference in ranges of temperature for supply of power to water pump or fan. The devices gives some
amount of heat, reason being casual application and there is a need for its temperature to decrease if we want to prevent its overheating. As shown in the figure 3, TEG which is connected to devices can use that heat which is produced by that electricity for heat sink in which heat goes and then we use that heat which is depicted in given system accurately.

Figure 3. Thermoelectric self cooling (Astrain et al 2012).

Now what we have to choose between TAC systems or thermoelectric self cooling depends on the difference in temperature ranges between the surface and environment of electronic devices with an aim to improve cooling efficiency.

2.4. Thermoelectric Material

TECT is also one of the also technology used for the transfer of heat in all types of electronic devices which do cooling. Reason being its advantages which are its not very difficult structures and it is not dynamic in nature. Also, this technology is one of the important technologies for energy that can be used again in applications by the application of solar radiations and energy of low range, also these types of production of materials of thermoelectric nature. The inorganic materials (e.g. PbTe, Bi₂Te₃) are used in research studies on thermoelectric which have great commercial application. These inorganic materials are the predictable thermoelectric material with ZT about 1. Various disadvantages are there like they not being eco friendly. They have less stability at ranges of temperature which are higher. This helps to use thermal energy which is otherwise hardly usable into productive applications as efficiently as possible.
3. Application of cooling which are thermoelectric in nature

Lots of usages of thermoelectric devices are there which help in the recovery of waste heat specially in automotive industry. It is also used to generate electric power. Some specific application are discussed in this paper.

3.1. Sensible air cool warm fan

An experiment on the applications of these types of modules which are thermoelectric in nature and is done for checking out the air supply which can either be heated or cooled of the predictable systems. It comprises of six plates which are thermoelectric in nature which contains boxes which are cold in nature of water and one box of hot water. The module which is thermoelectric in nature comprises of plates which are thermoelectric in nature, hot and boxes of water which are cold in nature. Results which we get from the level of heating of the fan system, the details of which are present and thoroughly matched with those atrocities from the old fan system that is one without these types of modules which are thermoelectric in nature. It also found that extreme temperature of water which we get from the module which is thermoelectric in nature at 70 and 12 degree, respectively. Also because of the varying temperatures that is cold in its respective weather and hot in its. Because of which older type of systems here has no use. So there is a need of temperatures to be hot and cold at their respective sides of the thermoelectric and then used judicially.

3.1.1. Fabrication of sensible air cool warm fan. One of the newest study which is conducted by S. Wiriyasarat et al. [8] in which fan (with module which is thermoelectric in nature) is studied. Results obtained from the same are then compared with the ones from the old fan system. Results got are expected, that they will guide the development of fan (with module which is thermoelectric in nature). Also it has high thermal performance.

![Figure 4. Representation of sensible air cool warm fan (Wiriyasarat et al. 2018).](image)

In summer, this type of modified fan is used in which water is taken by the help of water pump from water tank, which then flow into the coil which is cooled and it cools the supply of natural air. It then
move into the boxes of box which is cold and contains water of these types of modules. Coolant moves through same module into two hot boxes of water which is hot and flow into the mechanical device which help to regulate temperature and dissipate high temperature in the atmosphere which then comes into the hot water and absorbs warmth through hotterside of plate. Temperature in different portions of water which is cold and in the form of loop are calculated, by T -thermocouple, which gives precision of 0.1 percentages.

For winter, weather is maintained at normal temperature by the application of modified fan system. Hot water is then water tank, which then it goes into the coil and heats up the air supply (fan system). After that it flows in the heating module, which then absorbs heat from the hot water box. It comes back water tank in which hot water is present as depicted in figure 4. At the same time, coolant moves box of cold water of the module. It moves through the tank which contains water and is used for cooling and finally moves in box of water which is cold in nature.

3.1.2. Thermoelectric cooling and heating modules.TCM system need thrice boxes of water and six plates. The boxes of water are covered with long aluminium fins. The dimensions of these aluminium fins are 10×40×120mm. Each side of which is attached with water boxes. These are attached with the help of conductivity which is thermal in nature and high in range glue. This type of module system consists of boxes, twice in number of water and plates, thrice in number. The thermoelectric plates have dimensions of 40mm × 40mm × 3.75mm and is made up of bismuth tin (Bi-Sn). These types of plates having extreme temperatures that are 70°C and 60W have extreme level of cooling. Extreme temperature ranges are calculated by type T thermocouples with accuracy.

![Figure 5 Modified fan (Wiriyasarit et al 2018).](image)

3.2. Cooling system which is thermoelectric in nature and coupled with heat pipe

Refrigeration system, as we all know can be used in various types of fields. Dual functions, one is of refrigeration and other is of heating and which makes it prominent in all types of applications in engineering sector. Dryer of clothes was invented by Liu et al [9] used the heating model of the system which is thermoelectric in nature and heated. Refrigeration system has advantage of not causing any type of mechanical noise. It is also environmental friendly, has small size and also show sensitivity to temperature.
3.2.1 Fabrication of thermoelectric refrigeration. Refrigeration system’s model was presented by Yu Wang [10]. It’s base is presented by transfer of heat which is a dimensional. It also gives a platform for small systems which are thermoelectric in nature and are coupled with pipe which is heated. A spoiler duct is made by it which is helpful in increasing the working of the system which is cooled.

The mathematical model is presented on the basis of refrigeration cycle which is ideal in nature. Simplified calculation can be done for the same. Model is presumed that symmetric structure can be built. It can be used in analysis.

\[ \frac{d^2 T}{dx^2} + \frac{\rho T^2}{\lambda S^2} = 0 \]  
\[ \frac{dT}{dx} + \frac{1}{\lambda S} \int_{x}^{x+dx} \rho dx = 0 \]  

The first type of boundary conditions, 
\[ x=0, T=T_c; T=T_h; x=l. \]

Combining Equation (3) and Equation (4),
The temperature gradients can be expressed as,

\[
\frac{dT}{dx} = -\frac{\rho l^2}{\lambda S_2} (X) + \frac{1}{2} \frac{\rho l^2 L}{\lambda S_2} \left( \frac{T_H - T_c}{L} \right)
\]  

(5)

3.3. Solar still

Solar distillation still system is economically feasible in desalination of saline water. It is simple process as well as cost effective. It is non-polluting and free of cost. In this process, by the help of sun rays, water is evaporated which then falls on a condenser where it is cooled and desalinated.

| Sr No. | Chemical Property | Saline Water | Distilled Water |
|--------|-------------------|--------------|-----------------|
| 1      | pH                | 7.49         | 6.75            |
| 2      | E. conductivity   | 34800 µmhos/cm | 64 µmhos/cm    |
| 3      | Alkalinity        | 430 mg/l     | 16 mg/l         |
| 4      | Total Hardness    | 640 mg/l     | 6 mg/l          |
| 5      | Chlorides         | 17500 mg/l   | 10 mg/l         |

Solar Still system is used to give purified water which is used for drinking, for putting in different types of batteries, laboratories; also it is used in hospitals and in production of products which are commercialised. The idea of solar still first came in 1872 when one of the famous mining company needed pure water of drinking at a large scale and at a cheap rate. There are various techniques that can improve the working of solar still such as – any type of coating on inner surface, solar steel basin , use of surface coated with amalgam.
4. Opportunities for advancements

Thermoelectric materials result in the formation of TEMs. It is one of the main parts of thermoelectric cooler which is used for cooling. To increase its performance, we have to decrease its thermal conductivity. Also we have to increase its conductivity which is electrical in nature and also its seebeck coefficient which will help in getting higher figures of merit (ZT) value. The mixture of polymers which are organic with some materials which are inorganic is used to make films which are thin, in turn present the material as non isotropic. Designing this high thermal performance materials are cumbersome due to lack of theoretical basis. We have to improve it. Developments are going on and newer concepts are being developed like super lattice, plasma treatment etc. which is then used to higher the amount of ZT. To increase it above 4 is still difficult. Already researches are going on so that material becomes environment friendly and affordable. There is always scope of future development.

5. Conclusion

This work reviews the present researches which are done technology which is cooler and thermoelectric in nature. It gives us some idea of its usage in various cooling methodologies. It has a mode for cooling for different types of material. The observations are as follows:

This TECT system can be divided into two types i.e. TSC and TAC. Its performance is highly influenced by the materials which are thermoelectric in nature. These types of materials can be considered as valuable as bio thermal batteries. It is also present in solid state thermoelectric cooling and optoelectronic devices, space and automotive power generator. Higher the ZT value, better will the thermoelectric material. Numerous efforts has been done to improve the value of ZT. In the type of module which is thermoelectric in nature, a voltage, dc in nature is moved through the meeting point which is connected for the module, whose side is cooled and the other side is also heated. The results which we get from this type of fan system with module which is thermoelectric in nature. System are compared with those from the old fan system. The results which we get are expected to provide details that will help us to continue this development and designing the fan system with module which is thermoelectric in nature with performance of a higher notch. Solar still, invented in 1872 is thermoelectric active device which will help people in simplifying their day to day activities like desalination of water in an easy and cheaper way.

References

[1.] Y.Zhou, T.Zhang, F.Wang and Y.Yu 2018 Performance analysis of a novel thermoelectric assisted indirect evaporative cooling system Energy 162 299-308

[2.] Z.Liu, Y.Zhang, L.Zhang, Y.Luo, Z.Wu and J.Wu et al 2018 Modelling and simulation of a photovoltaic thermal compound thermoelectric ventilator system Appl. Energy 228 1887-1900

[3.] W.H Chen, C.C. Wang and C.I. Hung 2014 Geometric effect on cooling power and performance of an integrated thermoelectric generation –cooling system Energy Convers. Manag. 87 566-575

[4.] X.Li, S. Mahmoud, R.K. Al-Dadah and A. Elsayed 2014 Thermoelectric cooling devices integrated with pcm heat storage for MS patients Energy Procedia 61 2399-2402

[5.] Z.Liu, L.Zhang and G.Gong 2014 Experimental evaluation of solar thermoelectric cooled
ceiling combined with displacement ventilation system, *Energy Convers. Manag.* **87** 559-565

[6.] Y.Lou, L.Zhang, Z.Liu, Y.Wang, J.Wu and X.Wang 2016 Dynamic heat transfer modelling and parametric study of thermoelectric radiant cooling and heating panel system *Energy Convers. Manag* **124** 504-516

[7.] K.Irshad, K.Habib, F.Basrawi and B.B.Saha 2017 Study of a thermoelectric air duct system assisted by photovoltaic wall for space cooling in tropical climate *Energy* **119** 504-522

[8.] S.Wiriyasart, P.Naphon and C.Hommalee 2018 Sensible air cool-warm fan with thermoelectric module systems development Case Studies in thermal Engineering **13** 100369

[9.] D.Liu, F.Y. Zhao and G.F. Tang 2008 modelling and performance investigation of a closed type thermoelectric dryer *J.Drying Technology.* **26** 1208-1216

[10.] Yu Wang, Yushu Shi and Di Liu 2017 Performance analysis and experimental study on thermoelectric cooling system coupling with heat pipe *Procedia engineering* **20** 5871-878

[11.] Nurul Izzati Samasuddin, Salmiahs Ahmad, Nurul Fadzin Hasbullah and Siti Fauziah Toha 2013 Parametric system identification of thermoelectric cooler for single photon avalanche diode application. *Research Journal of Applied Sciences* **25** 712-719

[12.] David Astrain and Alvaro Martinez, 2012 Heat exchangers for thermoelectric devices,