The state of art review on thermal management techniques for the thermoelectric cooler

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Abstract

The usage of renewable energy sources and reducing the usage of fossil fuels are important to improve the quality of life and environment. Thermoelectric devices are direct energy conversion devices, which can be used for power generation, heat and cooling applications. Thermoelectric devices can be integrated with solar thermal systems, solar photovoltaic systems and waste heat recovery systems etc. to produce electrical energy and cooling effect. This article presents the state of art review on the thermal management techniques for thermoelectric cooler. The thermal management on TEC will improve the thermal performance of cooling power and Coefficient of performance.

1. Introduction

Cooling requirements in electronics, medicine, space application and buildings etc are continuously increasing. The conventional system used for cooling application is vapor compression refrigeration (VCR) system and vapor absorption refrigeration system (VAR). The refrigerants used in VCR and VAR system are the reason for global warming potential (GWP) and ozone depletion potential (ODP). To protect the environment, the cooling system without refrigerant can be used with the help of thermoelectric device. The thermoelectric device works based on seebeck and peltier effect. Thermoelectric device are two types, they are thermoelectric cooler (TEC) and thermoelectric generator (TEG). The TEC is solid-state direct energy conversion device convert electrical into thermal energy. The TEG work based on seebeck effect which convert heat into electrical energy. Thermoelectric device comprises of p-type and n-type semiconductor materials. The coefficient of performance (COP) of TEC is less compared to traditional cooling technology. The COP of TEC are the function of figure of merit (ZT) and temperature difference across the device. Therefore a strategy for improving the performance of TEC is required.

The performance of TEC can be improved by the proper thermal management approach. The COP, cooling capacity and cost are the three major selection of TEC. The increase in cold side
temperature and decrease in temperature difference (ΔT) leads to increase in cooling capacity. The COP of TEC is restricted by the cold side temperature (Tc) and hot side temperature (Th). To minimize the ΔT and maximize the COP in TEC it must controlled by the proper cooling Techniques. N Putra [1] used heat pipe as the cooling technique to achieve -10°C in vaccine carrier box using TEC. Matthew Redmond et al [2] used TEC as cooling medium in electronics, the hot spot region temperature drops to 9°C by passive cooling techniques. Paisarn Naphon and Songkran Wiriyasa [3] used mini rectangular fin heat sink and De-ionized water as coolant in TEC for controlling the central processing unit [CPU]. Chein and Huang [4] determined 0.054 °C/W is the required heat sink thermal resistance on hot side of TEC. Osot Khonsue [5] investigated the liquid cooling in the micro channel fin heat sink for TEC with mass flow rate are 0.023, 0.017 and 0.01 kg/s. Yu-Wei et al [6] determined the optimum input currents are from 6 A at 20W to 7 A at 100W heat load. N Putra and Iskandar [7] used Al2O3–H2O and TiO2–H2O nanofluids were used as the working fluid. The thermal performance of TEC is beneficial when the heat load is below 57W with water cooling system [8]. The TEC current, water inlet temperature, water flow velocity, and ambient temperature were studied to find the significant factor using taguchi method [9]. Xiaohui Lin et al [10] used TEC and microchannel Heat sink in thermal management of high power LEDs with water and nanofluids used as coolant. A.G. Agwu Nnanna et al [11] investigated Nanofluid-based heat exchanger 27-nm Al2O3–H2O nanofluid, the volume fraction varies between 0% and 2%. Chein and Chen [12] comments that by increasing the electrical current input and decreasing the heat sink thermal resistance, the minimum temperature can be obtained. Shahabeddin K.Mohammadian and Yuwen Zhang [13] investigated the thermal performance like COP and total entropy generation based on the effects of nano-particles diameter and nanofluids volume fraction. Dongliang Zhao and Gang Tan [14] used PCM as thermal management in TEC. The cooling COP is increased from 0.5 to 0.78 due to integration of PCM [15]. C Selvam et al [16] shows that Tc in TEC using pulse current got decreased from -14.5°C to -17.5°C due to Phase change material intergration.

This paper reviews about the various thermal management techniques used in TEC in order to improve the cooling power output and COP.

2. Thermal management types

![Figure 1: Thermal Management Techniques](image)
2.1 Active method

The active method need external agency to reduce the hot side temperature of the thermoelectric device eg: fan, pump, blower etc. The active method consists of two types air cooling method and liquid cooling method. The air cooling method uses fan operated by giving DC power. The liquid cooling method uses pump to circulate coolant like water or nano fluids under different mass flow rate. H.M Tu et al.[17] used components like heat sink with water block, water tank, DC brushless pump, fan and Heat exchanger. All these parts are connected by silicon tube. The active cooling system can be used in the severe environment.

2.2 Passive system

The passive system reduces the hotspot without any external device. The passive system consists of phase change material (PCM), heat pipes and fins with natural convection. There are variety of pcm’s are classified into three groups organic, inorganic and eutectic pcm.

2.2.1 Selection of PCM

(i) It is depend on the surrounding temperature and hot side temperature of TEC.

(ii) The liquid state temperature of PCM must be greater than surrounding temperature and lesser than the TEC hot side temperature.

(iii) It should be reliable, congruent melting, good nucleating properties and non-corrosive.

Table 1: List of PCM used in Thermal Management

| Passive Component | Specification/parameter                                      | comments                                                                 | Application | Reference |
|-------------------|--------------------------------------------------------------|--------------------------------------------------------------------------|-------------|-----------|
| RT22-PCM          | Melting temperature 19°C -23°C.                              | COP increased from 0.5 to 0.78 due to integration of thermoelectric cooling system with PCM heat storage. | TEC         | [14]      |
|                   | Heat storage capacity 200KJ/kg.                              |                                                                          |             |           |
|                   | Thermal conductivity-0.2 W/mK                               |                                                                          |             |           |
| OM32-PCM          | Melting temperature-32°C                                    | The cold side temperature is decreased from -14.5°C to -17.5°C with the square pulse current and PCM integration. | TEC         | [16]      |
|                   | Latent heat -191KJ/kg.                                      |                                                                          |             |           |
|                   | Thermal conductivity-0.250 W/mK                             |                                                                          |             |           |
| Capric acid (CH3 CH2 COOH) | Melting temperature-30.5°C                                 | Increase in voltage is observed when                                       | TEG         | [18]      |
|                   | Latent heat -159 KJ/kg.                                     |                                                                          |             |           |
Thermal conductivity- 0.15 W/mK  
the melting of PCM starts  
Latent heat -178 KJ/kg  
Thermal conductivity-0.2 W/mK  
The total amount of pcm absorb surplus heat immediately after thermal disturbance.

### 2.3 Hybrid system

It is the combination of active and passive system. This combination in TEC will improve the thermal performance of TEC. Eg: Copper heat sink with PCM under forced convection. The figure 2 shows that the hot spot of LED is reduced by cooling fins and forced convective device such as. This hybrid system will improve the heat transfer enhancement.

![Fig 2: The Hybrid system in thermal management [20].](image)

### 3. Thermal Management Techniques in TEC

Based on the literature survey, the thermal management techniques are classified into six types. They are given below as follows:

(i) Air Microchannel Heat sink-Natural convection  
(ii) Air Microchannel Heat sink-Forced convection  
(iii) Water Microchannel Heat sink  
(iv) Nano-fluid Microchannel Heat sink
(v) PCM with Heat sink

(vi) Heat pipes

3.1 Air Microchannel Heat sink-Natural convection

The air microchannel heat sink carried under the natural convection process. The heat transfer rate depends on the ambient conditions. Normally the heat transfer rate through natural convection is very slow but no external sources is needed. The fig 3 shows that in air microchannel heat sink the surface temperature $T_s$ exceed 100°C within two or three minutes from the starting period[9]. The increase in surface area of the natural convection heat sink cannot be recommended, Because increase in surface area of heat sink will not be much compatible for the application purpose.

![Image](image_url)

**Fig 3: The startup process of different cooling system [9]**

3.2 Air Microchannel Heat sink-Forced convection

The air microchannel heat sink under forced convection was studied with different input of TEC as shown in figure 4. The TEC input power varies from 2.91W to 94.5W. The DC supply of fan is about 3.3W. Based on forced convection techniques with input power of TEC shows that best one is 54W compared to 94.5W. The input power 94.5W generate huge joule heat compared to 54W under the same forced convection condition.
3.3 Water Microchannel Heat sink

The study shows that natural convection can be increased by increase in surface area of heat sink. But it is not compatible from the view point of application. Without any increase in surface area of heat sink the heat transfer rate can be used by the coolant such as water, glycol, nanofluids etc.,. The study has been carried with water microchannel heat sink with influence of four factors are inlet temperature of water, flow velocity of water, current and surrounding temperature. The schematic representation of thermal management techniques used in LED with combination of TEC is shown in figure 5.

Table 2: Comparison study of different factors for water microchannel heat sink [9]

| Factors                        | Forced convection parameters | Ts-min                  | Findings                                                                 |
|--------------------------------|------------------------------|-------------------------|--------------------------------------------------------------------------|
| Effect of Tec current          | u=3.44 m/s, Ti=25°C, and Ta =25°C | 15.6°C at 5A           | The surface temperature decreased from 47.3°C to 15.6°C as current increased from 1A to 5A. |
| Effect of inlet water temperature | Itec=4A, Ta=25°C, u=3.44 m/s | 20°C at Ti=25°C        | As inlet water temperature increases, the surface temperature also increases. |
| Effect of ambient temperature  | Itec=4A, Ti=25°C, u=3.44 m/s | 20°C at Ta=25°C        | As ambient temperature increases, the surface temperature also increases. |
| Effect of water flow velocity  | Itec=4A, Ti=Ta=25°C, u=3.5 m/s | 15°C at u=3.5 m/s      | As water flow velocity increases, the surface temperature decreases. |

Fig 4: Temperature versus time for different input power of TEC [20].
According to the table 5 significant effect are arranged from high to low Itec>Ti> Ta>u. The lowest factor is effect of water flow velocity. The effect of velocity on surrounding temperature is not significant because slope of the curve is relatively small as shown in figure 6. Therefore hot spot region can be controlled through Itec or Ti.

![LED Packages with cooling device](image)

**Fig 5:** LED Packages with cooling device [9].

![Velocity versus surrounding temperature](image)

**Fig 6:** Velocity versus surrounding temperature [9].

### 3.4 Nano-fluid Microchannel Heat sink

The enhancement in heat transfer through coolant can be increased by adding high thermal conductivity material like nano particles. The nanofluid is the combination of water and nanoparticles. The examples are TiO2, Al2O3 etc. The Particle size, volume fraction, and properties of nano particle and carrier fluid are the essential thermo-physical properties of Nano-fluid. The volume fraction of nano particle is the fraction between total volume and volume of nano particle whereas the total volume is the sum of volume of nano particles and...
volume of carrier fluid (base fluid). The author claims that $\Delta T$ temperature difference hot side and cold side is almost zero for nanofluid and $\Delta T > 0$ for water [11].

### 3.5 PCM with Heat sink

The PCM plays a significant role in the thermal management of TEC. The TEC hot side is provided with PCM and Heat sink. There are studies carried with the various fill volume of PCM in the heat sink. When the hot side of TEC increases to melting temperature of PCM, it starts to melt. During melting, the heat energy is stored and PCM will convert from solid to liquid. If hot side of TEC decreases, the melting temperature of PCM will decrease and phase will from liquid to solid. During freezing, the heat energy is released from the PCM. The author investigates that OM32 PCM with melting temperature of 32°C observed that the PCM height in the Heat sink increases, the COP of TEC decreases. The reason behind at higher fill volume is large amount of thermal energy is stored and dissipate heat at slower rate due to less value of thermal conductivity. [16]. The figure 7 shows that the copper heat sink with OM32 PCM.

![Fig 7: Thermoelectric cooler integrated with PCM[16].](image)

### 3.6 Heat pipes

Heat pipe is one of the thermal management tool to control the hot spot in the electronic and thermoelectric devices. The various author claims that heat pipe with nano fluids is found to be more effective in thermal management techniques. The figure 8 shows that comparison study had been carried between the water, Al2O3 and TiO2. The Al2O3 with 1% concentration found to be more effective than any other fluids [7].
Fig 8: Heat pipe nano fluid combined with TEC [7].

4. Conclusion

This paper reviews about the various thermal management techniques like Air Microchannel Heat sink, Water Microchannel Heat sink, Nano-fluid Microchannel Heat sink, PCM with Heat sink and Heat pipes. Normally air microchannel heat sink efficiency depends on the surface area. But there is a limitation to increase the surface area with application purpose. Air microchannel heat sink can overcome by water microchannel heat sink, the latter limitation is heat transfer property. To increase the heat transfer properly nano particles can be added in the water microchannel heat sink. On the other side PCM and heat pipe with nano fluids will be significant to enhance the improvement in thermal management techniques.

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