Applied Energy 143 (2015) 1–25

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Review

# Recent development and application of thermoelectric generator and cooler

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## HIGHLIGHTS

- Recent material research about the thermoelectric has been reviewed.
- Recent development and application in thermoelectric generator (TEG) has been reviewed.
- Recent development and application in thermoelectric cooler (TEC) has been reviewed.

## ARTICLE INFO

*Article history:*
Received 17 September 2014
Received in revised form 1 December 2014
Accepted 27 December 2014

*Keywords:*
Material researches of thermoelectric
Thermoelectric generator
Thermoelectric cooler
Recent application

## ABSTRACT

Energy crisis and environment deterioration are two major problems for 21st century. Thermoelectric device is a promising solution for those two problems. This review begins with the basic concepts of the thermoelectric and discusses its recent material researches about the figure of merit. It also reports the recent applications of the thermoelectric generator, including the structure optimization which significantly affects the thermoelectric generator, the low temperature recovery, the heat resource and its application area. Then it reports the recent application of the thermoelectric cooler including the thermoelectric model and its application area. It ends with the discussion of the further research direction.



**Contents**



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http://dx.doi.org/10.1016/j.apenergy.2014.12.075
0306-2619/

## 1. Introduction

Extensive fossil fuel consumption by human activities has led to serious atmospheric and environmental problems. Consequently, global warming, greenhouse gas emission, climate change, ozone layer depletion and acid rain terminologies have started to appear frequently in the literature. To abate the impact of the above disasters, the thermoelectric (TE) energy converters is proposed as one of the possible technologies for this aim, which currently gains the most popularity owing to its capability in converting the heat given off from vehicles, electrical instruments, etc., into the electricity.

The merits of this conversion lie in the solid-state operation, the gas-free emissions, the vast scalability, the maintenance-free operation without any moving parts and chemical reactions, no damage to the environment and a long life-span of reliable operation. In addition, the TE technology is reversible to transform the electrical energy into the thermal energy for the purpose of cooling or heating. However, the TE devices are still in the limited application mainly because of its low energy-conversion efficiency and the corresponding high material cost. As a result, extensive researches into the TE technology and its materials have been carried out in recent years for the achievement of the high energy-conversion efficiency and widespread application fields. This review therefore provides the overall review and the substantial discussion of the cutting-edge researches of the TE materials and their practical applications nowadays. This research work would help to illustrate the foundation of the TE technology, identify the technical barriers existing in current TE technology and propose the new thermoelectric topics/directions for future research.

The TE phenomenon was discovered in 18th century, which generates rather small voltage between two dissimilar metals and was mostly used as the thermocouples. With the invention of high-efficient semiconductor, the TE technology has experienced a rapid development over the last 60 years owing to its unique characteristics outstanding from traditional energy generator and cooler. Although new materials are still under the development, the basic theory behind the TE technologies are all depended upon the principles of Seebeck effect (main for power generation) and Peltier effect (main for refrigeration).

## 2. Working principles

Seebeck effect was found in 1821 which disclosed that two joint dissimilar metals have the different temperatures ($\Delta T$) at the joints, and the corresponding current and electromotive force existing in the joint circuit are called the thermo-current and thermo-electromotive force. Increasing the voltage difference ($\Delta V$) enlarges the temperature difference between two joints ($\Delta T$). The proportional constant related to the intrinsic property of the material is known as the Seebeck coefficient. This coefficient is relatively low for materials like metals at approximately 0 μV/K, while it would be much larger at around ±200 μV/K for the semiconductor.

$$\alpha = \Delta V/\Delta T \tag{1}$$

Peltier effect, which was discovered in 1834, is the phenomena that when there is the current in the circuit, the joint of different conductors absorbs or rejects the heat depending on the direction of the current. This phenomenon is largely due to the difference of the Fermi energies between two materials. The capacity of the heat absorption or rejection is largely related to the property of the two dissimilar conductors and the temperature of the joint. When defining the heat absorbed in per area of the joint per second, a dimensionless parameter, ZT, is usually used to determine the Peltier performance of a thermoelectric material.

$$\mathrm{ZT} = \frac{\alpha^2}{\kappa}\sigma T \tag{2}$$

where $\alpha$ is the Seebeck coefficient, $\sigma$ is the electrical conductivity, $\kappa$ is the thermal conductivity which can be divided into two parts ($\kappa_e$ and $\kappa_l$, the electrical and lattice respectively) and $T$ is the temperature.

As a result, the TE technology can be divided into two categories according to the Seebeck and Peltier respectively: (1) thermoelectric generator (TEG) for power generation when the two materials are exposed in different temperatures, as shown in Fig. 1; (2) thermoelectric cooler (TEC) for cooling when the voltage is added onto the two materials as indicated in Fig. 2.

The TEG efficiency can be estimated by:

$$\eta_{\max} = \frac{T_H - T_C}{T_H} \cdot \frac{\sqrt{1+\mathrm{ZT}} - 1}{\sqrt{1+\mathrm{ZT}} + \frac{T_C}{T_H}} \tag{3}$$

where $T_C$ is the cold side temperature and $T_H$ is the hot side temperature.

The maximum coefficient of the performance (COP) of the TEC is approximately given by:

$$\mathrm{COP}_{\max} = \frac{T_C}{T_H - T_C} \cdot \frac{\sqrt{1+\mathrm{ZT}} - \frac{T_H}{T_C}}{\sqrt{1+\mathrm{ZT}} + 1} \tag{4}$$

According to Eqs. (3) and (4), when the ZT is infinite, the efficiency or COP is the Carnot [1]. Therefore, there is one theory claims that thermoelectric generators are Carnot hot engines, where electrons perform as the working medium.

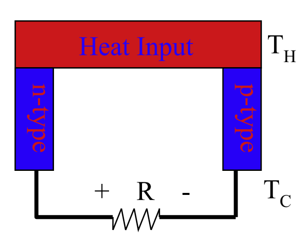


**Fig. 1.** The schematic diagram of thermoelectric generator.

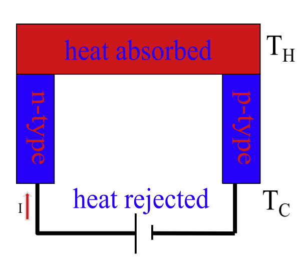


**Fig. 2.** The schematic diagram of thermoelectric cooler.