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Performance Optimization of Thermoelectric Cooler Using Genetic Algorithm

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ABSTRACT

Thermoelectric coolers (TECs) use the Peltier effect for thermal management of electronic devices. They offer high reliability and low noise operation but limited in use due to low performance. In the present work, through the use of a genetic algorithm (GA), two single-objective optimizations associated with two separate objectives are carried out, aiming maximization of cooling capacity and maximization of the coefficient of performance (*COP*) of TEC with space restrictions. Interfacial thermal resistance and electrical contact resistance are taken into consideration to obtain a more realistic model. This paper presents a new approach to finding appropriate solutions by optimally arranging the length of n-type and p-type thermoelectric (TE) elements, the cross-sectional area of TE elements, and input electric current. To validate the GA predictions, three-dimensional steady-state TEC models are prepared, and finite-element simulations are carried out using ANSYS®. Close agreement between the GA and ANSYS® has been observed. This study provides a new mathematical optimization model that is more realistic and is quite close to the physical construction of TEC modules manufactured by industry.

1. INTRODUCTION

The solid-state thermoelectric (TE) technology attract great attention of the researchers because of its potential use as green energy conversion devices. The Peltier effect of thermoelectric technology offers direct conversion of electrical energy into temperature difference. Conversely, the Seebeck effect of TE technology provides the conversion of thermal energy of temperature differential into electric power [1]. A thermoelectric cooler (TEC) dissipates the heat and removes the hotspots of the electronic devices in an environment-friendly manner using the Peltier effect. A TEC could be installed easily within a restricted space due to its practical manufacturing possibility in small sizes. Thermoelectric coolers must be appropriately designed and manufactured to meet the necessary performance requirements. Two essential performance parameters of a TEC are the cooling capacity and the coefficient of performance. The cooling capacity of thermoelectric coolers ranges from milliwatts to watts depending on the requirements. The maximum cooling effect or higher *COP* for a thermoelectric cooler can be achieved through upgraded TE materials and improved device design.

The efficiency of TE materials increases with a material property known as figure of merit (Z). The term Z is defined as α^2/RK, where α is the Seebeck coefficient, R is the electrical resistance, K is the thermal conductance. With absolute temperature (T), the dimensionless figure of merit (ZT) is used to characterize TE materials. A higher value of ZT corresponds to better cooling performance. Hicks et al. described that the value of ZT could be enhanced by reducing the dimensions of thermoelectric materials [2, 3]. At room temperature, Venkatasubramanian et al. [4] reported a ZT~2.4 for p-type Bi_2Te_3/Sb_2Te_3 superlattice devices. Peak ZT values of different TE materials are attainable at different temperatures. Over the past two decades, significant progress in maximizing ZT has been made in developing thermoelectric materials [5-10].

With the significant ongoing efforts to improve TE materials, the researchers also focus on designing and assembling the TECs. The investigations established that the geometric structure of thermoelectric elements affects the performance of thermoelectric coolers [11-15]. Huang et al. [16] combined a three dimensional TEC model with a simplified conjugate-gradient technique. They reported that at a fixed temperature difference and fixed current, a substantial value of the total area of TE elements with small element length can maximize cooling capacity. Yang et al. [17] reported that micro-thermoelectric coolers operating in a transient regime could provide a better cooling effect. Nain et al. [18] reported that a suitable value of dimensionless current can enhance the performance of TEC. Pareto-optimal solutions were obtained for different settings of temperature ratio. Shen et al. [19] reported that a two-segmented TE element structure can reduce the joule heating effect from 50% to 35% on the cold side. The results showed a remarkable 118.1% improvement in maximum cooling capacity. Nain et al. [20] optimized cooling capacity and *COP* performance of TEC using dimensional structural parameters as design variables. The geometrical parameters were optimized to find Pareto-optimal solutions. Jeong [21] reported that the *COP* of TEC can be increased by optimal values of current and length of thermoelements. Lee [22] proposed a dimensional analysis approach to find out the optimal design of TE devices with feasible mechanical constraints. Mijangos et al. [23] reported a novel design of asymmetrical legs to enhance the performance of TE devices.