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Design and Numerical Evaluation of Cascade-Type Thermoelectric Modules

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Thermoelectric (TE) generation performance can be enhanced by stacking several TE modules (so-called cascade-type modules). This work presents a design method to optimize the cascade structure for maximum power output. A one-dimensional model was first analyzed to optimize the TE element dimensions by considering the heat balance including conductive heat transfer, Peltier heat, and Joule heat, assuming constant temperatures at all TE junctions. The number of *p*–*n* pairs was successively optimized to obtain maximum power. The power output increased by 1.24 times, from 12.7 W in a conventional model to 15.7 W in the optimized model. Secondly, a two-dimensional numerical calculation based on the finite-volume method was used to evaluate the temperature and electric potential distributions. Voltage–current characteristics were calculated, the maximum power output was evaluated, and the efficiencies of two possible models were compared to select the optimal design. The one-dimensional analytical approach is effective for a rough design, and multidimensional numerical calculation is effective for evaluating the dimensions and performance of cascade-type TE modules in detail.

Key words: Thermoelectric generation, cascade module, numerical simulation, optimization, heat transfer

List of Symbols

Variables

- T Temperature (K)
- Q_h Heat transfer rate from heat source to hot surface of cascade module (W)
- Q_c Heat transfer rate from cold surface of cascade module to heat sink (W)
- P Output power of cascade module (W)
- η Conversion efficiency (–); = P/Q_h
- n Number of *p*–*n* pairs in single-stage module (–)
- m Number of stages in multistage cascade module (–)
- d Leg length of TE element (m)
- a Cross-sectional area of TE element (m^2)
- l Ratio of a to d (m); = a/d
- S Relative Seebeck coefficient ($V\ K^{-1}$)
- ρ Electric resistivity (Ω m)
- λ Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
- K Thermal conductance ($W\ K^{-1}$)
- R Electric resistance (Ω)
- R_L External load (Ω)
- I Current (A)
- E Electromotive force (V)
- V Electric potential (V)
- $\mathbf{J}$ Current density ($A\ m^{-2}$)

Subscript

- i *i*th stage from hot side in multistage cascade module

Superscripts

- p *p*-type material
- n *n*-type material

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INTRODUCTION

Thermoelectric (TE) generation based on the Seebeck effect can directly convert heat into electricity.