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Modeling analysis of longitudinal thermoelectric energy harvester in low temperature waste heat recovery applications

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HIGHLIGHTS

- A new LTEH model is proposed and validated under transient and steady-state conditions.
- The thermoelectric energy harvester model is developed in TRNSYS.
- Comparison of simulation and experimental results shows great accuracy.
- The new TRNSYS component can be used as a design tool.

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ABSTRACT

The worldwide interest in thermoelectric waste heat recovery is constantly growing, with a wide range of applications ranging from small harvesters integrated into wireless sensor networks all the way to larger harvesters such as the ones that can potentially be integrated into cars. The wide range of applications makes a requirement for studying the dynamic response of TEGs. The aim of this work is to develop a mathematical model to accurately simulate the thermal and electrical behaviours of a longitudinal thermoelectric energy harvester (LTEH). In order to implement the theoretical analysis, a new TRNSYS component has been developed so this new model can also be used as a design tool.

The LTEH model presented in this paper is validated through the comparison of results between theoretical analysis and experimental data. Testing results and discussion show the reasonability of this new model and also their use as a simulation tool.

1. Introduction

Energy recovery techniques have become significantly demanding since it makes an important contribution towards reducing the greenhouse gases which cause global warming. Energy recovery includes any technique or method that converts waste energy (i.e. thermal, chemical or mechanical energy) into another kind of energy which can be reused for other energy purposes (i.e. electrical energy).

Research activities in energy recovery from waste heat using thermoelectric effect have considerably increased since the 1990s. There are recently reported researches such as thermoelectric power generation from CPU waste heat [1], Si–Ge based TEGs applied to gasoline engine vehicles [2], bismuth telluride based TEGs applied to automotive exhaust systems (AETEG) [3,4], thermoelectric power generation systems applied to generate electricity from municipal waste heat [5], a thermoelectric power generator using solar heating [6] and so on.

At the same time, many mathematical models and approaches for simulating a heat exchanger that utilizes thermoelectric modules for power generation has been designed. The majority of these models apply general heat transfer techniques in cohesion with thermoelectric module equations for a system level analysis.

Bohn developed one of the earliest models in 1981 [7]. It is an extension of the effectiveness-number of transfer units (ε-NTU) method for heat exchanger analysis. The model implements thermoelectric generator equations into the common ε-NTU equations by setting up a dimensionless ratio of actual power generated to the maximum possible power generation. An example case is provided for a parallel flow configuration with promising results; however, there is no experimental testing to validate the model. The Esarte et al. model [8] also uses ε-NTU method to simplify calculations. They set up an energy balance with a hot and cold side heat exchanger with a thermoelectric module in between

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Nomenclature

Abbreviation

TEG	thermoelectric generator
LTEH	longitudinal thermoelectric energy harvester
np	number of TEGs in parallel
ns	number of TEGs in series
t	time (s)

Symbols

N	number of thermocouples
α	Seebeck coefficient (V/K)
σ	electrical resistivity (Ωm)
e	length (m)
A	cross sectional area (m^2)
ρ	material density (kg(m^3)
S	specific heat capacity (J/kg K)
λ	thermal conductivity (W/m K)
$\dot{m}$	mass flow rate (kg/h)
h	convective heat transfer coefficient (W/m^2 K)
Q	heat rate (W)
V	electric voltage (V)
I	electric current (A)
P	electric power (W)
η	efficiency (%)
R	electric resistance (Ω)
T	temperature (K)
y	axis coordinate (m)

Subscript

hh	hot side heat exchanger
tc1,2,3	thermal compound
ce	ceramic substrate
ch	cold side heat exchanger
cl	copper lid
H	hot side
C	cold side
p	p-type semiconductor
n	n-type semiconductor
in	input
out	output
L	load resistance
amb	ambient air
AVG	average
i	stage number
j	row number
f	fluid
k	iteration number

and studied the influence of fluid flow rate, heat exchanger geometry, fluid properties and inlet temperatures on the power supplied by the thermoelectric generator. The Work could provide some guidelines for determining the optimum operating parameters of thermoelectric generator, however, limited experimental results are provided. Crane and Jackson investigated thermoelectric waste heat recovery with regards to cross flow heat exchangers [9,10]. A cross flow heat exchanger model was validated against measured performance of advanced cross flow heat exchangers without thermoelectrics. The numerical simulations were compared to experimental data with good agreement between them. Yu and Zhao [11] developed a numerical model for prediction of performance

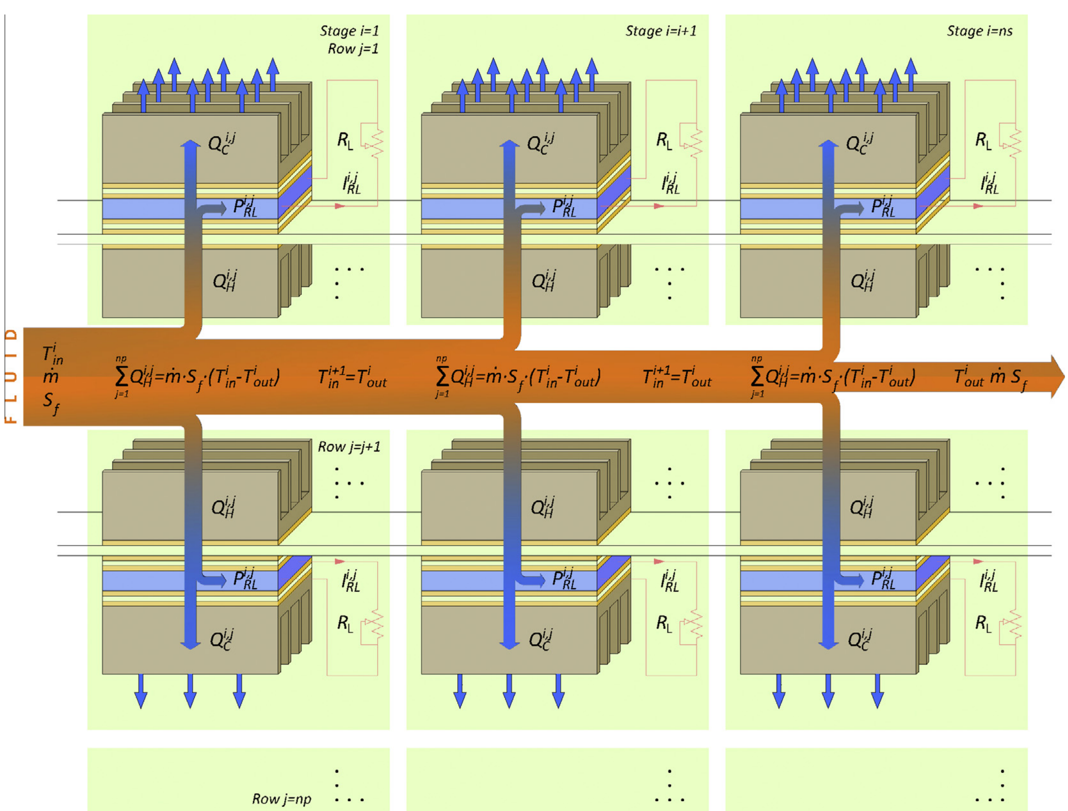

Fig. 1. Heat transfer model of longitudinal thermoelectric energy harvester LTEH.