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Role of surface radiation on the functionality of thermoelectric cooler with heat sink

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HIGHLIGHTS

- Nowhere the performance of TEC has been evaluated considering the heat sink to be emitting thermal radiation.
- There is a shift in the operating points of the TEC for all level of currents when radiation is considered.
- The non-functional zone comes closer to the operating zone for radiation for the second working temperature range.

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ABSTRACT

The present investigation substantiates the inclusion of radiation heat transfer coming from heat sink while modelling the thermal performance of a thermo-electric cooler (TEC). A commercial grade thermoelectric cooler from Laird Technology and a heat sink from Aavid Thermal Alloy are chosen to perform this study and their actual values revealed by the respective company datasheets have been considered for the comparison. The results provided in the company datasheets are based on the assumption that the heat sink is mounted on the TEC and is cooled by natural convection only. Therefore, the present study conducted in this work, also identifies the heat transfer solely due to natural convection. The results are validated against the available operational company datasheets. Subsequently, the effect of surface radiation from the heat sink in addition to the natural convection on the thermal performance of TEC has been investigated. Furthermore, to bring more clarity in the investigation, two different ranges of working temperatures have been opted and shift in the operational points because of radiation in both ranges have been delineated through data tables, figures and comparative plots.

1. Introduction

In spite of high cost and poor power efficiency, thermoelectric cooling is appreciated as it is considered to be an environment friendly refrigeration technology i.e. “Green refrigeration technology” for small scale localized cooling applications such as in computers, infrared detectors, electronics and optoelectronics applications. A thermoelectric refrigerator is a solid-state active cooler which transfers heat from the cold junction to the hot junction connected by two different semiconductor materials continuously being actuated by the direction of the current (widely known as Peltier effect).

Relevant few literatures have been referred in this context and are discussed in the following. Yang et al. [1] have described the transient response of TEC with and without mass load through examination of both the minimum temperature reached and the time constant involved in the cooling and recovering stages. Chang et al. [2] investigated that the total thermal resistance of the thermoelectric cooler (R_{TEC}) increases with heat load and decreases with input current, whereas thermal resistance in the heat sink (R_{hs}) increases with input current and decreases with heat load. In their study, they further evaluated the overall resistance (i.e. $R_t = R_{TEC} + R_{hs}$) under every heating power and input current. Due to contrary trends of R_{TEC} and R_{hs} for input current, they could find an existence of optimal input current for each R_t. Huang and Duang [3] theoretically have solved a linear dynamic model of the thermoelectric cooler including the heat sink and the cooling load heat exchanger using small signal linearization method. Yushanov et al [4] have numerically solved the governing equations related to the

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Nomenclature

A	Exposed surface area to ambient (m^2)
C	k*G (W/K)
COP	Coefficient of performance
F	View factor
G	Geometry factor (m)
h	Heat transfer coefficient (W/m^2K)
H	Height of the heat sink fin (m)
I	Applied current at TEC (A)
k	Thermal conductivity of air (W/mK)
L	Length of the heat sink fin (m)
N	Number of n-type & p-type couples in the TEC
Nu	Nusselt number
n	Number of fins of the heat sink
Q	Heat transferred (W)
R	Thermal resistance (K/W)
R′	Electrical resistance of the TE material (Ω)
Ra	Rayleigh number
S	Gap between fins of the heat sink (m)
T	Absolute temperature (K)
t	Thickness (m)
W	Width of heat sink base (m)
Z	Figure of merit (K^{-1})

Greek alphabets

α	Seebeck coefficient (V/K)
ρ	Electrical resistivity (Ωm)
η	Overall surface efficiency of heat sink fins
ε	Emissivity of the heat sink surface
σ	Stefan–Boltzmann constant (5.67×10^{-8}) ($W/m^2 K^4$)

Subscripts

a	Ambient
b	Heat sink base
c	convective
ch	Heat sink channel
h	Hot side of TEC
hs	Heat sink
l	cold side of TEC
nc	Numerical code
r	radiative
sa	Sink to ambient
t	Total

thermoelectric phenomenon using COMSOL multi physics commercial tool, where they studied the effect of the temperature dependent material properties of the p and n type semiconductors. Felgner and Frey [5] have shown a transient thermal analysis of both thermoelectric coolers and thermoelectric generator built in Modelica language where it has been considered that the material properties vary with 1D spatial temperature distribution. Lossec et al [6] have demonstrated how the electricity produced from human body by attaching a thermoelectric generator can be maximized and with regard to this, they introduced a new factor Z_E which takes into account not only the physical characteristics of the thermoelectric materials but also the quality of thermal coupling involved.

But, in none of the papers cited above, the performance of TEC has been evaluated considering the heat sink fins to be emitting thermal radiation.

Therefore, this study is focussed to trace the crucial effects that a TEC encounters due to thermal radiation by the attached heat sink.

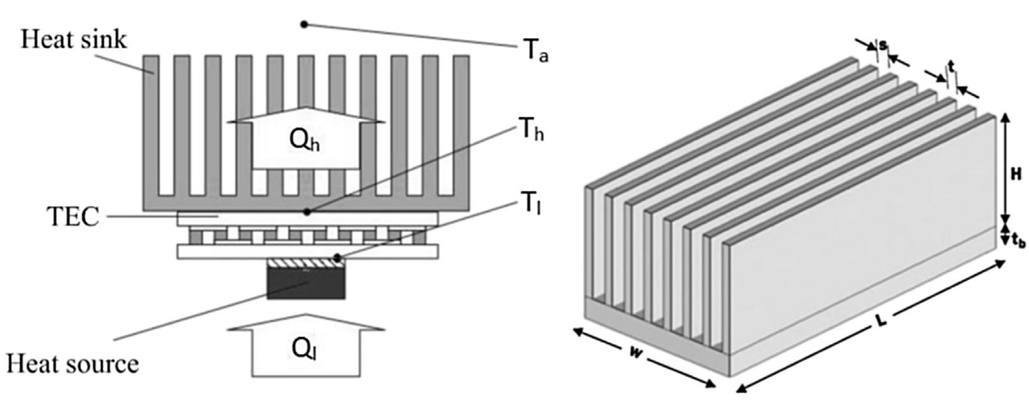
2. Governing equations and computational procedure

A thermoelectric cooler Fig. 1a consists of a thermoelectric module, a heat sink connected to the hot side, where as a heat exchanger connected to the cold side subjected to a cooling load. The thermoelectric module comprises of many pairs of p-n type thermoelectric material connected in series and clamped and soldered with two base plates. The cooling load Q_l is absorbed at the cooling end of the heat exchanger and subsequently conducted to the hot end plate (i.e. hot side of the TEC).

The following Equations (1) and (2) express heat load at the two junctions, which are given as:

$$Q_l = N\left\{ \propto T_l I - \frac{1}{2} I^2 R' - C(T_h - T_l) \right\} \quad (1)$$

$$Q_h = N\left\{ \propto T_h I + \frac{1}{2} I^2 R' - C(T_h - T_l) \right\} \quad (2)$$



(a) (b)

Fig. 1. Basic schematic of a thermoelectric cooler with heat sink.