Renewable Energy 131 (2019) 308–317

Contents lists available at ScienceDirect

Renewable Energy

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

A comprehensive exergy analysis of a prototype Peltier air-cooler; experimental investigation

Hamed Sadighi Dizaji*, Samad Jafarmadar, Shahram Khalilarya, Samira Pourhedayat

Department of Mechanical Engineering, Urmia University, Urmia, Iran

ARTICLE INFO

Article history:
Received 11 February 2018
Received in revised form
9 July 2018
Accepted 12 July 2018
Available online 17 July 2018

Keywords:
Thermoelectric
Cooling
Coefficient of performance
Air cooler
Peltier

ABSTRACT

Thermoelectric coolers have been abundantly investigated from the viewpoint of the first law of thermodynamic. However, extremely few exergy analysis have been probed for thermoelectric air-coolers. Because of the importance of exergy consideration in each thermodynamic process, this paper experimentally focuses on the effect of various parameters on exergy destruction and the second law performance through a thermoelectric air cooler. The effects of flow and thermodynamic parameters including air flow rate, incoming air temperature, water flow rate, incoming water temperature, DC voltage/ampere etc. on exergetic characteristics are clarified in this study. Interesting meaningful curve behavior was observed for exergetic performance of thermoelectric cooler. Indeed, curve behavior of exergetic performance is descending-ascending and therefore a critical value of DC voltage was found in which the amount of second law performance has a minimum/maximum value. Increment of air flow rate improved the exergetic performance of Peltier-air cooler. Besides, higher air inlet temperature reduced exergy destruction of thermoelectric module (TEM) which means that Peltier air cooler is appropriate for regions with warmer weather in comparison with moderate climates.

1. Introduction

Most recently, researchers would like to produce thermoelectric technology as a novel cooling method because of its inevitable advantages in comparison with compression refrigeration systems. Lack of compressor, refrigerator, moving parts and so on can be considered as the most important advantages of thermoelectric cooling technique. Thus, researchers enthusiastically try to enhance the coefficient of performance (COP) of thermoelectric coolers. Performance improvement methods of thermoelectric module (TEM) can be classified into two main parts. The first part is related to the materials by which the n/p type conductors of thermoelectric are made. All other effective parameters including heat sinks, flow and thermodynamic conditions etc. are arranged in the second part. However, most researchers have evaluated the TEM effectiveness from the view point of the first law of thermodynamic only. Although, Seebeck coefficient and figure of merit ZT are meant to quantify the entropy production and transport, studies on the exergetic feature of the cooling application of thermoelectric are relatively immature comparing with that on energetic aspect.

Previous investigations of thermoelectric modules can be classified into two main parts. The major portion of former thermoelectric studies has focused on power generation via thermoelectric and a smaller percentage has focused on cooling/heating production using thermoelectric module. Since the main aim of this paper is cooling process of thermoelectric, the literature review focuses on cooling application of thermoelectric and not power generation.

Mathiprakasam and Heenan [1] analytically evaluated the use of thermoelectric as an automobile air conditioning system. The required electrical power was provided via solar cells on the ceiling of the car. Their results showed that, the required electrical power for cooling capacity of 4 kW is around 9.5 kW. Maneewan et al. [2] experimentally studied the cooling characteristics of a thermoelectric cooler. Both hot and cold sides of TEM were connected to heat-sink and fan. Three thermoelectric modules were used in their experiments and optimum condition was observed at electrical current of “1” ampere. Tipsaenporm et al. [3] tried to enhance the performance of thermoelectric cooler via direct evaporative cooling of hot side of TEM. Cooling performance of their system was obtained between 72% and 81%. Its cooling capacity was enhanced from 53 W to 74 W using the direct evaporative cooling. Andersent

* Corresponding author.
E-mail addresses: HamedSadighiDizaji@gmail.com, St_H.Sadighi@Urmia.ac.ir (H. Sadighi Dizaji), S.jafarmadar@Urmia.ac.ir (S. Jafarmadar), Sh.Khalilarya@Urmia.ac.ir (S. Khalilarya), Samira.Pourhedayat@gmail.com (S. Pourhedayat).

https://doi.org/10.1016/j.renene.2018.07.056
0960-1481/

Nomenclature

COP	Coefficient of performance ($\frac{q_c}{Ex_s}$)
Ex_d	Exergy destruction, W
Ex_i	Exergy input to the system, W
Ex_o	Exergy output of the system, W
Ex_s	Input electrical power, W
I	Electrical current, A
I_{max}	Data sheet parameter. The current that provides a temperature difference of ΔT_{max} under a specific T_h and heat flux$q_c = 0$, A
K_m	Thermal conductivity of TEC, W/mK
N	Number of couples
q_c	Cooling power of TEM, W
q_h	Heating power of TEM, W
R_m	Electrical resistance of TEC, Ω
T	Temperature, K
T_h	Temperature of the hot side of the TEM, K
T_c	Temperature of the cold side of the TEM, K
T_o	Surrounding temperature, K
T_w	Water inlet temperature, K
TEC	Thermoelectric cooler
TEM	Thermoelectric module
V	Voltage, V
V_{max}	Data sheet parameter. The voltage drop across the TECs' terminals, corresponding to current I_{max} and the temperature difference ΔT_{max}, V

Greece symbols

η_{Ex}	Second law performance
α_m	Seebeck coefficient (V/K) of TEC
ΔT	Temperature difference, K
ΔT_{max}	Data sheet parameter. The largest temperature differential that can be obtained between the hot and cold ceramic plates of a TEC for the given level of T_h and $q_c = 0$, K

[4] designed and studied a thermoelectric air conditioning system for submarines. Alomair et al. [5] analytically and experimentally investigated the solar thermoelectric air cooler. Maximum COP was achieved around 1.7 at 1 A and also increment of electrical current reduced the amount of COP. Chang [6] analyzed the thermal parameters of a thermoelectric air cooler. The hot side of their thermoelectric was cooled by a fan too. The effects of electrical current and thermal power applied to cold side were studied. According to their findings, there is an optimum electrical current in which the maximum cooling power of cooler is achieved. Indeed, both lower and higher electrical current decrease the cooling power of TEM. Gillott et al. [7] analytically evaluated the cooling behavior of a small-scale thermoelectric cooler. Thermoelectric was assumed between two aluminum heat-sinks. Similar to other studies, cooling capacity and COP was increased and decreased respectively with increment of electrical current. Liu et al. [8] presented the heating/cooling characteristics of a thermoelectric air cooler which was designed for production of both cold air and warm water. Heat generated form the hot side of TEM was transformed into a water flow via some helical tubes. It was revealed that, if this system is appropriately adjusted, it can provide required warm water without reduction of its cooling capacity. The value of cooling COP and heating COP were obtained 2.59 and 3.01 when the system was used as a source of water heat pipe. They believed that, this system can be considered as an environmentally friend device which can produce both cold air and warm water. In the second part of that study, it was tried to use the solar call in order to provide required electrical power for their system. Miranda et al. [9] proposed the use of thermoelectric as an air cooler for electrical automobiles. They believed that, compressor-based cooling systems is not suitable for electrical cars from the view point of economic condition and thermal performance so that they increase the production cost and reduce the quality of electrical automobiles. Hence, they considered the thermoelectric as a promising method for air cooling process of such cars. Obviously, the required electrical power of these coolers should be produced by solar cells or other sources. Consier et al. [10], numerically and experimentally probed the production of hot and cold air by TEM. They used four thermoelectric modules. The hot side of the system was adjusted by a water heat exchanger. They showed that, TEM can be used as the heating/cooling unit with acceptable COP. Riffat and Qiu [11] designed and analyzed a cylindrical heat-sink for thermoelectric air coolers. They believe that the TEM air coolers have many advantages. However, lower values of COP have been caused reduction of their application. Two main effective parameters on COP of TEM are thermoelectric material and optimum heat-sink. Astrain et al. [12] tried to improve the COP of thermoelectric refrigerator by optimizing the heat dissipation of hot side of TEM. They improved the thermal resistance of the used heat-sink up to 36%. Simultaneous use of thermosiphon and phase-change enhanced the COP of the system up to 23%. Manoj and Walke [13] investigated the employment of TEM as an automobile air cooler. Said study focused on India in which replacement of other type of air cooler with CFC-based coolers are necessary [13]. Sadighi Dizaji et al. [14] experimentally investigated the effect of thermal-fluid parameters on a prototype air cooler. Dia et al. [15] presented new configurations of transcritical CO_2 refrigeration cycle combined with a thermoelectric sub-cooler and an expander. Irshad et al. [16] experimentally and numerically evaluated a novel thermoelectric air duct system which works based on photovoltaic under Malaysian weather condition. Shen et al. [17] carried out a parametric study of thermoelectric radiant cooling and heating panel. Zhu and Yu [18] optimized the rectangular heat-sink of thermoelectric from the view point of the second law of thermodynamic. As described before, the literature review of this research has focused on cooling production by TEM not power generation. However, the main selected studies which have focused on power generation by TEM can be found in Refs. [19–42].

According to above literature review, studies on the cooling application of thermoelectric from the viewpoint of the second law of thermodynamic are relatively immature comparing with that on first law of thermodynamic. Particularly, extremely few experimental exergetic analysis of thermoelectric air coolers have been carried out. Thus, in this experimental study, the effects of flow and thermodynamic parameters on exergetic characteristics of a thermoelectric air cooler are clarified. All tested parameters have been varied and recorded in a logical range via high accurate instruments as described in the following.

2. Experiments

2.1. Experimental set-up and test section

A general view of the experimental set-up is shown in Fig. 1. Six standard commercial thermoelectric modules were used in this study. Air fluid was flowed into the cold side of TEM and water flow