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An exhaustive experimental study of a novel air-water based thermoelectric cooling unit

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HIGHLIGHTS

- A novel air-water based thermoelectric cooling unit is experimentally investigated.
- Different climate conditions are simulated using of different air flow rates and temperatures.
- Various parameters are evaluated to find optimum condition.
- COP/COP_{max} is studied as a new consideration and memorable behavior was observed.

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ABSTRACT

In this paper, the cooling feasibility of air flow via a novel air-water based TEC system (as an alternative air cooling unit) is experimentally investigated for different climate conditions. Contrary to previous studies, thermoelectric hot side temperature was adjusted by a low constant water flow rate (and not by an air fan) which significantly increased the cold side performance of TEM. Ten parameters including $T_{a,inlet}$, $T_{w,inlet}$, $T_{a,outlet}$, $T_{w,outlet}$, T_c, T_a, $\dot{m}_a, \dot{m}_w$ and DC voltage and DC current were directly recorded by measurement instruments during the experiments. Six other parameters including q_c, q_h, COP_c, COP_{max}, COP_c/COP_{max} and q_{air} were evaluated by formulas and correlations using of aforesaid measured data. Five numbers of aforementioned parameters were variant parameters. Indeed, the effect of $\dot{m}_a, \dot{m}_w$, DC voltage/current and $T_{a,inlet}$ (variant parameters) on other impressionable parameters were investigated in present study. Optimum working condition was evaluated from a new point of view. Indeed, in this paper, it was accidently found out that, despite the descending behavior of both COP_c and COP_{max} (due to changing of variants), the ratio of said parameters (COP_c/COP_{max}) creates a peak point (ascending and then descending) in all cases. Said peak point can be considered as an appropriate working condition of thermoelectric units. Findings showed that, the cold side of thermoelectric system can act as an applicable air cooling system especially when the hot side of thermoelectric is cooled by a current liquid such as water.

1. Introduction

Contrary to conventional cooling units (compression refrigeration cycle) which comprise moving parts such as compressor, thermoelectric cooling units do not require any moving part. To that reason, TEC systems are recently considered as one of the most popular cooling units by researchers. Indeed, according to Peltier effect, applying a DC voltage between two electrodes of TEM causes heating generation on one side of TEM and cooling generation on the other side of TEM. Cold surface of TEM can be employed as a cooling unit in other applications such as refrigerators, electronic components, air conditioning systems, photovoltaic equipment and so on. Thermoelectric cooling system can be considered as one of the most affordable cooling units by utilization of renewable methods such as photovoltaic modules as a required energy provider of TEM. According to Seebeck effect, thermoelectric modules can be used vice versa in order to produce electrical energy. Indeed, electricity generation is another application of thermoelectric which can be obtained by applying a temperature difference between two sides of TEM. The main studies on thermoelectric cooling systems in ten recent years are chronologically summarized as below.

Lineykin and Ben-Yaakov [1] proposed a graphical method for calculating the steady state operational point of a thermoelectric

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Nomenclature

C	specific heat, J/kg K
COP	coefficient of performance
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/m K
LPM	liter per minute
$\dot{m}$	mass flow rate, kg/s
P	input electrical power, W
q	heat transfer rate, W
q_a	heat transfer rate between air fluid and cold surface of TEM
q_{ph}	Peltier heating, W
q_{pc}	Peltier cooling, W
q_j	Joule heating, W
q_{con}	Fourier heating, W
q_c	cooling power of TEM, W
q_h	heating power of TEM, W
Q	volumetric air flow rate, LPM
R_m	electrical resistance of TEC, Ω
T	temperature, K
T_h	temperature of the hot side of the TEC, K
T_c	temperature of the cold side of the TEC, 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
W	total uncertainty in the measurement
X	independent variable

Greece symbols

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

Subscripts

a	air
c	cold
con	Fourier heating
j	Joule heating
h	hot
max	maximum
ph	Peltier heating
pc	Peltier cooling
w	water

cooler. The method could help designers to examine and choose a thermoelectric module from catalogs to meet a specific cooling problem. Cosnier et al. [2] performed an experimental and numerical study on a thermoelectric module that cools or warms an air flow. The experimental results confirmed the feasibility of cooling or heating air through thermoelectric modules. The application of nanofluids as the working fluid on a heat pipe liquid-block combined with thermoelectric cooling was investigated by Putra et al. [3]. The higher thermal performance heat pipe liquid-block and thermoelectric cooled system with nanofluids proved its potential as a working fluid in said study. Calise et al. [4] investigated on optimal thermoeconomic configuration of Solar Heating and Cooling systems. Chen et al. [5] numerically studied on the performance of miniature thermoelectric cooler affected by Thomson effect. The obtained results suggested that the cooling power of a thermoelectric cooling module with Thomson effect can be improved by a factor of 5–7%. Zhou and Yu [6] presented a theoretical model for the optimization of a thermoelectric cooling system in which the thermal conductances from the hot and cold sides of the system are taken into account. The analysis results showed that the maximum coefficient of performance (COP) and the maximum cooling capacity of the TEC system can be obtained when the finite total thermal conductance is optimally allocated. Zhu et al. [7] focused on the optimal heat exchanger configuration of a TEC system. The effects of total heat transfer area allocation ratio, thermal conductance of the TEC hot and cold side and TEM element material properties on the cooling performance of the TEC were investigated in detailed based on the developed mathematical model. Their results revealed that the heat transfer area allocation ratio is an applicable characteristic of optimum design for TEC systems. Feasibility study of a green energy powered thermoelectric chip based air conditioner for electric vehicles were performed by Miranda et al. [8]. It was seen that the TEC air conditioning cooling system can be switched to a heating pump with simple current reversal at the p and n junctions of the TEC module. He et al. [9] theoretically and experimentally investigated on a thermoelectric cooling and heating system driven by solar. The formulation of the classical basic equations for a thermoelectric cooler from the Thomson relations to the non-linear differential equation with Onsager's reciprocal relations was performed by Lee [10] to basically study the Thomson effect in conjunction with the ideal equation. The comparison between the exact solutions and the ideal equation on the cooling power and the coefficient of performance over a wide range of temperature differences showed close agreement. In conclusion, the Thomson effect was small for typical commercial thermoelectric coolers and the ideal equation effectively predicts the performance. Russel et al. [11] examined the performance of a thermoelectric cooler (TEC) based thermal management system for an electronic packaging design that operates under a range of ambient conditions and system loads using a standard model for the TEC and a thermal resistance network for the other components. The results showed that there is a tradeoff between the extent of off peak heat fluxes and ambient temperatures when the system can be operated at a low power penalty region and the maximum capacity of the system. A prototype thermoelectric system integrated with PCM (phase change material) heat storage unit for space cooling has been introduced by Zhao and Tan [12]. An experimental evaluation of a solar thermoelectric cooled ceiling combined with displacement ventilation system was conducted by Liu et al. [13]. The results show that the total heat flux and COP of the panel are strongly influenced by operating voltage, ambient temperature and indoor temperature. Yildirim et al. [14] experimentally investigated on a portable desalination unit configured by a thermoelectric cooler. Geometric effect on cooling power and performance of an integrated thermoelectric generation-cooling system was studied by Chen et al. [15]. When the lengths of TEG and TEC vary, the maximum reduction percentages of system performance were 12.45% and 18.67%, respectively. Optimization performance analysis of a thermoelectric refrigerator with external heat transfer was performed by Ding et al. [16].