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Application of thermoelectric as an instant running-water cooler; experimental study under different operating conditions

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HIGHLIGHTS

- A continuous-instant running water cooler by thermoelectric is proposed.
- A novel thermoelectric pack is designed and no water reservoir is required.
- The effects of water flow rates on heating/cooling characteristics are evaluated.
- The effects of DC voltage and inlet temperatures are discussed.
- Present system was found as a novel promising water cooler.

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ABSTRACT

Current water coolers contain a water reservoir which always deal with hygienic problems because of accumulation of bacteria, etc. Furthermore, based on sanitary laws, the tubes contained CFC (in current water coolers) cannot be placed inside the water fluid and must be welded on the outer surface of the reservoir which causes reduction of the performance of cooling process. Besides, the limit capacity of reservoirs does not allow them to provide continues chilled water. Hence, this paper hopes to clarify the fabrication feasibility of a water cooler which provides continuous-instant chilled water (without requirement of any reservoir) by thermoelectric power and find its appropriate working condition. In other words, such cooler does not use electrical power while nobody requires chilled water. Once the valve of the cooler is opened, the running water fluid is directly and instantaneously cooled after passing through a thermoelectric pack which overcomes all aforesaid issues. For this aim, two water flows are injected into the two sides of a novel thermoelectric unit and a comprehensive experimental analysis of the system is performed under different operating conditions. The amounts of outlet temperatures, surfaces-temperature, COP, heat transfer rate, etc. are evaluated and discussed to find the suitable working condition. It was concluded that the feasibility of instant water cooler is possible with a compatible value of COP if the value of effective parameters are selected appropriately.

1. Introduction

Recently, thermoelectricity is considered as a promising cooling/heating method for different applications. Indeed, temperature of one side of thermoelectric module (TEM) is reduced and the other side is increased by applying a DC voltage. The theory under this phenomenon is termed Peltier effect. Researches enthusiastically would like to employ the TEM as a cooling unit instead of former methods (compression cycles, etc.) because of some remarkable reasons including lack of moving parts, no requirement of refrigerant, reliability, longevity, etc. Regardless the mechanical and electrical engineers, other academic fields such as environmental science are interested in TEM as well because of its clean features. Before the explanation of the main aims and features of the present investigation, some previous cooling applications and researches of TEM are briefly summarized as below.

He et al. [1] numerically studied the impact of various cooling techniques on thermoelectric generator (TEG) effectiveness. Shen et al. [2] theoretically evaluated the performance of annular thermoelectric. Ahemmed et al. [3] experimentally evaluated the thermoelectric cooling of an electronic device using nano-fluid. They observed that, increment of nano-fluid concentration improves the thermal performance of TEM cooling system and they proposed the nano-fluid as a promising coolant for thermoelectric. Hogblom et al. [4] presented a framework to simulate the TEG systems so that it was able to predict the performance of system accurately and efficiently. Shen et al. [5] studied the thermoelectric application in net zero energy buildings. Their

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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/mK
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
θ_m	defined in Eq. (10) as $\frac{1}{K_m}$

Subscripts

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

results indicated that sufficient heating/cooling supply is available by thermoelectric module to ensure thermal comfort. Attar and Lee [6] designed and tested an automotive air-to-air thermoelectric air conditioner. Karwa et al. [7] worked on thermal resistances of heat sink which affect the coefficient of performance (COP) of thermoelectric coolers. They demonstrated a low thermal resistance water cooled heat sink design for hot side of commercial low-cost thermoelectric refrigerator. A comprehensive analytical exergy-economic investigation on thermoelectric heat pump was performed by Nemati et al. [8]. Lv et al. [9] suggested a new design-concept for TEM cooler with combination of two-stage structure and super-cooling effect. Based on their outcomes, if a step current pulse is supplied to a two-stage thermoelectric cooler (TEC), a better cold temperature drop, a weaker temperature overshoot, and a longer holding time of super-cooling state are obtained. Lin et al. [10] experimentally studied the cooling performance of a two-stage thermoelectric module. Zhang and Xuan [11] investigated the effect of thermal resistance on a highly concentrated photovoltaic-thermoelectric hybrid system. Both the output power and the temperature distribution in the hybrid system are calculated by means of a three-dimensional numerical model. They indicated that, there are two major factors in the thermal design of the highly concentrated PV-TE hybrid system: (1) the thermal resistance between the PV and the TE, (2) the thermal resistance between the TEM and the environment. Cai et al. [12] tried to reduce the temperature of electronic devices by thermoelectric. They focused on the impact of thermoelectric specifications on COP of TEM under various operating conditions in order to achieve the effective cooling operating mode. Dia et al. [13] presented new configurations of transcritical CO_2 refrigeration cycle combined with a thermoelectric sub-cooler and an expander. Martinez et al. [14] studied the combination of heat pipe exchangers and thermoelectric self-cooling, and demonstrated its applicability to the cooling of power electronics. Simulation tests have indicated that simple system modifications allow relevant improvements in the cooling power. Allouhi et al. [15] presented a theoretical analysis of a thermoelectric heating system (THS) coupled with an office room situated in Fez (Morocco). The studied THS can help in reducing up to 64% of energy use in the office room compared to the conventional electric heater. Al-Madhhachi and Min [16] tried to produce drinkable water by thermoelectric. Indeed, hot surface of TEM was used to evaporation of water and the cold surface was employed for vapor condensation. Rezania and Rosendahl [17] designed a hybrid thermoelectric-photovoltaic system and tested under wide range of solar concentration. Their results revealed that, the hybrid system is more efficient than the single photovoltaic system for TEM materials with ZT ≈ 1. Irshad et al. [18] experimentally and numerically evaluated a novel thermoelectric air duct system which works based on photovoltaic. The aim of research was cooling under Malaysian weather condition. Shen et al. [19] carried out a parametric study of thermoelectric radiant cooling and heating panel. Heenan [20] 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. [21] were 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 were used in their experiments and optimum condition was observed at 1 Ampere. Tipsaenporm et al. [22] 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 by using direct evaporative cooling. Andersent [23] designed and studied a thermoelectric air conditioning system for submarines. Alomair et al. [24] analytically and experimentally investigated the solar thermoelectric air cooler. Maximum COP was achieved around 1.7 at 1 Ampere and also increment of electrical current reduced the amount of COP. Chang [25] analyze the thermal parameters of a thermoelectric air cooler. The hot side of their thermoelectric was cooled by fan too. 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