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Experimental performance investigation of minichannel water cooled-thermoelectric refrigerator

Murat Gökçek*, Fatih Şahin

Department of Mechanical Engineering, Faculty of Engineering, Ömer Halisdemir University, Campus, 51100 Nigde, Turkey

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ABSTRACT

An experimental performance analysis of minichannel water cooled-thermoelectric refrigerator in this study is presented. The cooling system of refrigerator is consists of two thermoelectric modules integrated with the minichannel heat sinks in its hot side and the heat dissipaters in its cold side. The experiments carried out for different system voltages and different flow rates of cooling water in the minichannel. The results show that the inner temperature of water cooled-thermoelectric refrigerator is about 2 °C for 0.8 L/min flow rate while it is about −0.1 °C for 1.5 L/min flow rate at the end of 2-h experiment. COP value of thermoelectric refrigerator is 0.23 in the flow rate 1.5 L/min while COP is 0.19 in the flow rate 0.8 L/min at the end of 25 min cooling times. When it comes to 8 V system voltages, COP of the thermoelectric refrigerator is about 0.41 at the end of 25 min operating period for the flow rate 1.5 L/min. This study concludes that the performance of minichannel heat sink used in this study has as good as other liquid water cooled systems used to absorb heat from thermoelectric modules hot side.

1. Introduction

Refrigeration is an important process for many applications, ranging from fresh keeping the perishable food products to the wide variety of the temperature controllers used in electronics and other industrial fields [1,2]. In conventional domestic refrigerators are used the vapor-compression technology. The refrigerators based on vapor compression have a high coefficient of performance (COP) but the refrigerants used in such systems have detrimental effects on the global environmental. Thermoelectric refrigeration based on the Peltier effect has important advantages compared to conventional vapor technology in spite of the fact that its COP is not as high a vapor compression technology [3,4]. Some of these can be listed: free of refrigerant, the using of electrons as refrigerant, more compact system state, lower noise and vibrations, high quality temperature control and less maintenance requirements. In addition, they possess advantage it can be powered by direct current (DC) electric sources as photovoltaic cells [5,6].

Nowadays, the application areas of thermoelectric cooling include thermoelectric refrigeration, electronic and automobile cooling, thermoelectric air-conditioning, photovoltaic-thermoelectric hybrid system, active building envelope system and fresh water production etc. [5]. In the design of thermoelectric cooling systems, the cooling power and COP are two important performance indicators, and the COP of overall system effects significantly from the COP of the thermoelectric module used in the applications [5]. There are several methods foremost the enhancements of thermoelectric cooling system performance. It can be classified as thermoelectric module design (thermoelement length, number of thermocouples etc.), thermal design (heat sink geometry, allocation of heat transfer area, and more effective heat sinks etc.) and the refining of operational conditions of thermoelectric cooling system

Abbreviations: COP, coefficient of performance; CP, cooling-down period

* Corresponding author.
E-mail address: mgokcek@ohu.edu.tr (M. Gökçek).

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Nomenclature

A	surface area, [m^2]
Cp	specific heat of the product, [kJ/kgK]
hext	heat transfer coefficient at the outer surface, [W/m^2K]
hint	heat transfer coefficient at the inner surface, [W/m^2K]
k	thermal conductivity, [W/mK]
L	thickness, [m]
m	mass of the food product, [kg]
M	number of independent variables, [-]
Nu	Nusselt number, [-]
Pr	Prandtl number, [-]
$\dot{Q}_c$	heat flow entering the cabinet of refrigerator, [W]
$\dot{Q}_{pl}$	product load, [W]
$\dot{Q}_T$	total rate of heat gain of a refrigerated space, [W]
Re	Reynolds number, [-]
T_{amb}	outside air temperature, [K]
$T_{\text{int }1}$	temperature on cold side heat dissipater, [K]
$T_{\text{int }2}$	temperature inside the refrigerated space, [K]
Tpf	final temperatures of product, [K]
Tpi	initial temperatures of product, [K]
U	overall heat transfer coefficients, [W/m^2K]
$\dot{W}_e$	power consumed by experimental system, [W]
$\dot{W}_{fan}$	heat generated by the fan, [W]
X	variable, [-]

Greek symbols

δR	uncertainties associated with dependent
Δt	time interval
ΔT_{oi}	the inner/outer temperature difference of the thermoelectric refrigerator
δX	independent variable

Subscripts

i	specific parameter number

(heat sink coolant, mass flow rate of coolant etc.) [5]. In the past years, various articles and reports have been presented on evaluating the performance of thermoelectric refrigerators. Min and Row [7] conducted experimental evaluation of prototype thermoelectric refrigerators and evaluated their cooling performances by considering COP values, cooling down rates. The COP was found around 0.3–0.5 for typical operating temperature at 5 °C with ambient at 25 °C. Results also show that its COP is possibly after enhancements in module contact resistances, thermal interfaces and effectiveness of heat exchangers. Astrain et al. [8], developed a computational model for thermoelectric refrigerator based on Peltiers effect and its application to a refrigerator with an inner volume of 0.055 m^3 analyzed. They found that the accuracy of the model was acceptable and a maximum error for COP was ± 7% and maximum discrepancy for thermal drop 1.2 K. Dai et al. [9] conducted an experimental study for thermoelectric refrigerator driven by photovoltaic module with battery storage. Their results revealed that the refrigerator can maintain the temperature at 5–10 °C, and have a COP about 0.3. Abdul-Wahab et al. [10] designed a portable solar thermoelectric refrigerator for using rural areas. This refrigerator was experimentally tested for various operating parameters. They reported that the inner temperature of the refrigeration area was reduced form 27–5 °C in approximately 44 min. In their study, COP was calculated as about 0.16. Vián and Astrain [11] developed a thermoelectric refrigerator whose cooling system consisted of two thermoelectric modules and two-phase thermosiphons and capillary lift with a single compartment of 0.225 m^3 for food preservation at 5 °C. Their results indicated that by using two phase-devices into the refrigerator was increased the COP by 66% compared with finned heat dissipater. Jugsujinda et. al. [12] analyzed performance of thermoelectric refrigerator with an inner volume of 0.022 m^3 by considering time, current, temperature and COP. Results indicated that the cold side temperature of cooling unit in refrigerator was decreased from 30 °C to −4.2 °C for 1 h and the COP of refrigerator was calculated as 0.65. An experimental and simulation studies on development of a hybrid refrigerator with three compartments (refrigerator at 5 °C, super-conservation at 0 °C, and freezer at −20 °C) that combined thermoelectric and vapor compression technologies were performed by Vián and Astrain [13]. Thermoelectric system was used for the super-conservation compartment. They concluded that the temperature of super-conservation compartment was kept constant at 0 °C, even if the

Table 1
Performance summary of the several thermoelectric refrigerators reported in the literature.

Volume (m^3)	Module power (W) - number	ΔT_{oi} (°C)[a]	COP	CDP (min)	Hot side heat sink	Cold side heat sink	Ref.
0.013	9.5-10	22	0.16	50	Air source, forced	Air source, forced	[10]
0.225	50-1	11.2	0.39	–	Phase change thermosypon	Thermosypon porous media	[16]
		14.67	0.29		Phase change thermosypon	Finned heat sink	
0.115	52-1	10	0.3	120	Liquid heat exchanger	Finned heat sink	[7]
0.04	120-1	16	0.2	45	Liquid heat exchanger	Liquid heat exchanger	[7]
0.055	50-1	23.9	–	–	Air source, forced	Air source, forced	[8]
0.021	76-1	–	0.19	60	Air source, forced	Finned heat sink	[12]
8.3×10^{-5}	–	17.6	0.1	70	Air source, forced	Planar heat pipe	[15]
0.225	50-2	18.9	0.23	–	Thermosypon with two phase	Thermosypon with two phase and capillary lift and with cold extender	[11]

[a] ΔT_{oi} is the inner/outer temperature difference of the thermoelectric refrigerator.