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OPERATION OF A SYSTEM WITH THERMOELECTRIC MODULE APPLIED TO COOLING AN EXPERIMENTAL ROOM

DZIAŁANIE UKŁADU Z OGNIWEM TERMOELEKTRYCZNYM ZASTOSOWANYM DO CHŁODZENIA KOMORY BADAWCZEJ

Abstract: Thermoelectric modules (TE), also called Peltier modules, can be used for the cooling processes in various system configurations. The thermoelectric modules act as a heat pump - supplying electrical energy to the TE module causes energy transport from its one side, called the cold side, to the other one, called the hot side. The effects of the Peltier module operation depend on the applied heat exchangers type and the intensity of the current supplied to the module. In this paper, the operation of a selected thermoelectric module used for cooling experimental room of a 0.125 m^3 is presented. The heat exchangers, consisting of aluminum radiators integrated with fans, were used to improve the heat exchange process on both sides of the applied TE module. During the tests, the temperature changes inside the experimental room and on the heat sinks on the cold and the hot sides of the TE module at variable current supply from 4 to 6 A were followed. The best results of cooling performance were obtained with 4 and 5 A currents. In these cases, the temperature inside the experimental room was reduced by approx. 9 °C.

Keywords: thermoelectric module, Peltier module, cooling effect

Introduction

Thermoelectric (TE) modules are solid-state devices used commonly as cooling units (TEC) and power generators (TEG) [1, 2]. A single TE module consist of a number of *n*-type and *p*-type semiconductor junctions connected electrically in series (by cooper conductors) and thermally in parallel. Semiconductors are placed between two ceramic plates, which forms two sides of the module: cold and hot. A schematic diagram of TE module construction is presented in Figure 1. The performance of thermoelectric module is described by five physical phenomena comprising three thermoelectric effects: Pelter effect, Seebeck effect (the opposite phenomenon to the Peltier effect, used in thermoelectric power generators), Thomson effect as well as Joule effect and heat conduction [1]. Thermoelectric cooling phenomenon, allowed by these devices, is described by the Peltier effect. According to this physical phenomenon, when TE module is powered by direct current (DC) it creates the heat transfer between two electrical junctions. On the one side (known commonly as the cold side) of the TE module heat is being absorbed from the surrounding environment - when electrons flow from a low energy level in the *p*-type material to a higher energy level in the *n*-type material, which requires energy supply, the energy is absorbed on the *p*-*n* junction causing the cooling effect. On the other side of TE module (called usually as the hot side) heat is deposited and released to the environment as a result of electrons returning from higher energy level in the *n*-type to a lower energy level in the *p*-type material. When the current direction changes, the effect is reversed [4-6].

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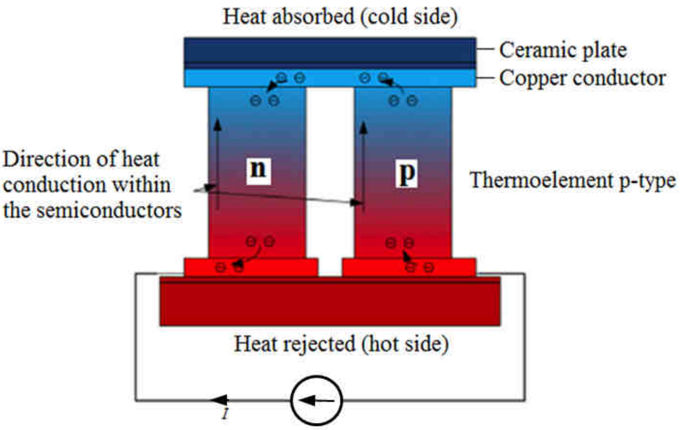

Fig. 1. Schematic diagram of TE module construction [3]

The amount of the energy gained on the hot side of TE module is greater than the amount of energy absorbed from the environment on the cold side because of the Joule's heat - when electric current flow through the TE module (conductor of non-zero resistance) additional heat is generated in the module and transported both, partially, to the hot side and to the cold side. Both, Joule's heat and thermal conduction (see Fig. 1), influence the cooling process negatively [1, 6].

The Thomson effect describes a phenomenon related to one leg within the TE module and influences heat production, heat transfer and energy conversion. Depending on the temperature difference between the hot and cold leg ends and the Seebeck coefficient value of the leg material, it can either depressed or promoted the performance of TE module [7-9].

Summarizing all of the previously described phenomena, the performance of thermoelectric cooling device depends on a following factors [1, 6-9]:

- the properties of the thermoelectric material including Seebeck coefficient, electrical conductivity and thermal conductivity - those properties are used to determine the primary criterion of merit ZT value; the most commonly used thermoelectric material based on bismuth telluride (Bi_2Te_3) is characterized by ZT value of 1,
- the value of electric current applied to the TE module,
- the temperature values of the hot and cold sides of TE module,
- the thermal resistance of the heat sink on the cold and, what the most important, hot side of the TE module.

Refrigeration process based on thermoelectric technology, in comparison to conventional refrigeration, presents several significant advantages including: simplicity of use, compact size of the devices, lack of moving parts, lover levels of noise and vibration, lack of refrigerant and small cooling capacities.

Thermoelectric devices are mainly used for cooling objects such as microprocessors, graphics cards, laser diodes or even photovoltaic panels [10-12]. They are also used in laboratory equipment, in medical application (e.g. for tissue preparation and storage) and tourist refrigerators [13]. There is also a possibility to use TE module to in ventilation and air conditioning systems of buildings [14-18].

Liu et al. [14] developed the novel thermoelectric cooled ceiling combined with displacement ventilation system, called by the authors STCC-DV. The system allows on heating and cooling the space, and both cooled ceiling and ventilation systems are supplied by photovoltaic installation. The experiment concerning the application of cooled ceiling, where commercial TE modules were used, showed that the performance of tested system strongly depends on operating voltage and temperatures. In conducted experiment, the values of *Coefficient of performance* (*COP*) equal 0.9 and 1.9 were reached for voltage of 5 and 4 V respectively.

In the another research, Liu et al. [15] designed the solar thermoelectric air conditioner with hot water supply (STACHWS). The tested system can work in several modes according the users' requirement. The recovery of condensing heat, utilization of heat from the hot side of TE module and fluent control of work parameters allowed to reach *COP* equal 4.51 in space cooling and air heating mode, therefore it was stated that tested STACHWS system can bring the reduction of indoor cooling and heating load and provide the continuous hot water supply for the users.

An interesting study was performed by Wiriyasart et al. [16]. The authors developed air cooling and heating system for ventilation purposes, which was based on several water heat exchangers working at both sides of thermoelectric modules. Cooling module consisted of six thermoelectric plates, two cold water boxes and a hot water box, while heating module included three TE modules, one hot water tank and one cold water tank. The remaining heat from cooling module was dissipated to the atmosphere. It allowed to heat the air flux by 2.5 °C and cool it by 2 °C. No data on *COP* was included in this study.

The novel facade-integrated thermoelectric air conditioning was developed by Matuska et al. [17]. The system integrated the functions of heating, cooling (by ventilation) and shading within the standard curtain walling module and was supply by *PV* panels and flat-plate batteries. Described system was powered by DC with control of parameters based on actual temperature conditions. Presentation of performance included experimental cooling and heating of an office room with dimensions 5.4 m x 3.5 m x 4 m, while the facade unit dimensions were 1.8 m x 2.8 m x 0.2 m. The several input DC parameters were tested, which resulted in the range of *COP* for heating mode 1.2 to 3.3 and for cooling mode 0.35 to 2.5.

In the newest work of Liu et al. [18] a solar-driven exhaust air thermoelectric heat pump recovery (SDEATHP) system was presented. The SDEATHP was developed in order to overcome the limitations of the passive waste heat recovery systems and the active waste heat recovery systems. In the tested system, a solar *PV* panel converted solar radiation into electrical energy, which was afterwards used to power the exhaust air thermoelectric heat pump recovery (EATHP) system to recover the energy for fresh air heating or cooling. The advantage of the system is the lack of power consumption, except required for the applied fans. TE modules are supplied directly from the *PV* panel, which allows to save investment costs (no batteries and inverter). The EATHP system is consisted of two (fresh and exhaust air) fans, two heat sinks and thermoelectric modules installed between the fresh air side heat sink and the exhaust air side heat sink. As heat sinks, heat pipes were used. The system is strongly dependent on the external conditions (temperature and solar radiation), therefore the reported *COP* varied during the experiment and reached values between 1.26 and 5.6 for heating mode and 0.51 and 14.2 for cooling mode, respectively.

The aim of this paper was to evaluate the relation between the temperature values achieved in monitored points of small-scale cooling system with TE module tested under the laboratory condition. In the conducted experiment, TE module was powered by different values of electric current: 4, 5 and 6 A.

Materials and methods

The scheme of applied laboratory installation allowing tests of thermoelectric module is presented in Figure 2. The cuboid experimental room consisted of 5 cm thick polystyrene boards characterized by thermal conductivity coefficient of 0.034 W/(m·K). The cubature of the experimental room was equal to 0.125 m^3 (internal room dimensions are 0.5 m x 0.5 m x 0.5 m). The connections of room walls were additionally insulated with the carefully applied layer of polyurethane foam. In the conducted research study, the thermoelectric module QC-127-1.4-8.5MD (Quick-Cool) was used. The basic parameters of the applied TE module are as following: maximum amperage 8.5 A, maximum voltage 15.5 V and the maximum temperature difference between the hot and cold sides 70 °C. The module dimensions were 40 mm x 40 mm x 3.4 mm. On the both sides of the TE module the aluminum heat sinks integrated with fans were installed to ensure the forced convention heat transfer. The heat exchangers were attached to the tested TE module by thermal conductive paste of a conductivity of 5.6 W/(m·K). This created construction was placed in the top cover of the room in order to ensure thermal insulation of the TE module. The direction of the current was set in order to provide cooling of the experimental room. There were no heat gains inside the experimental room.

The measurements applied in the presented study covered observation of air temperature changes inside the experimental room as well as temperature on the cold and hot sides of the TE module, in three repetitions, during time duration of 90 minutes for three selected values of the applied electric current: 4, 5 and 6 A, respectively.

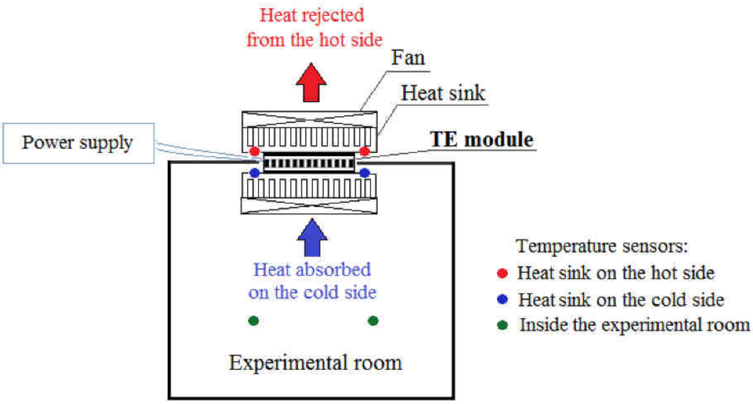

Fig. 2. Schematic diagram of experimental setup with temperature sensors

The developed system of measurement as well as data recording and logging allowing control of the air temperature changes inside the experimental room and temperature changes on the heat sinks on the cold and hot sides of TE module consisted of the following elements:

- two stainless steel temperature sensors Pt500 (measuring accuracy ± 0.1 °C), for measuring the temperature inside the experimental room,
- four copper plate temperature sensors Pt500 (measuring accuracy ± 0.1 °C) for temperature measurement on the cold and hot side of the TE module,
- data logger APEK AL.154 (Poland).

The location of previously described sensors in the experimental room and on the both surfaces of the TE module is presented in Figure 2.

The obtained results of temperature measurements for all applied value of power supply current were statistically validated using the standard correlation matrices for a given current, while the possible differences in the observed values of temperature for each of applied currents were assessed by the Kruskal-Wallis one-way analysis of variance, after application of the Shapiro-Wilk test of normality.

Experimental results and discussion

The changes of temperature in a monitored points of the experimental sets at different currents applied to the TE module are presented in Figure 3.

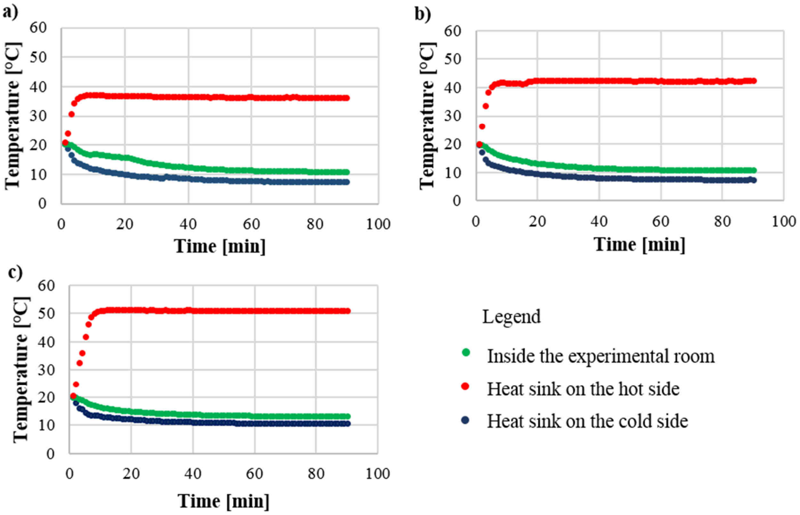

Fig. 3. Temperature changes in the monitored points for different currents: a) 4 A, b) 5 A, c) 6 A

In all the tested cases, the trends of curves visible in Figure 3 are analogous. The measured temperature in all monitored points of the system changes dynamically in the first ten minutes of the experiment and stabilizes eventually until the full time duration of the experiment.

The average temperature obtained in monitored locations for a given values of applied current and the values of obtained standard error for the mean are presented in Figure 4.

The air temperature values inside the experimental room obtained at the end of the experiments for assumed current values 4, 5 and 6 A are 11, 10.9, 13.4 °C accordingly. The temperature values achieved on the hot side are 36.4, 42.4 and 51.1 °C, and the temperature values on the cold side are 7.4, 7.6, 10.8 °C, respectively. It can be noticed that the higher values of current applied to the TE module the higher temperature values on the hot side was registered, what is related to the Joule's heat increasing the energy gains on the hot side. In case of value 6 A of current applied to the tested TE module, the additional amount of Joule's heat influenced the cooling process negatively. The applied heat exchanger is not efficient enough to remove the excess heat generated on the hot side of the module. Thus, part of this heat is conducted to the cold side minimizing the cooling capacity. The relations between the temperature values on the hot side and the air temperature values inside the chamber, achieved in all tested series, are presented in Figure 5.

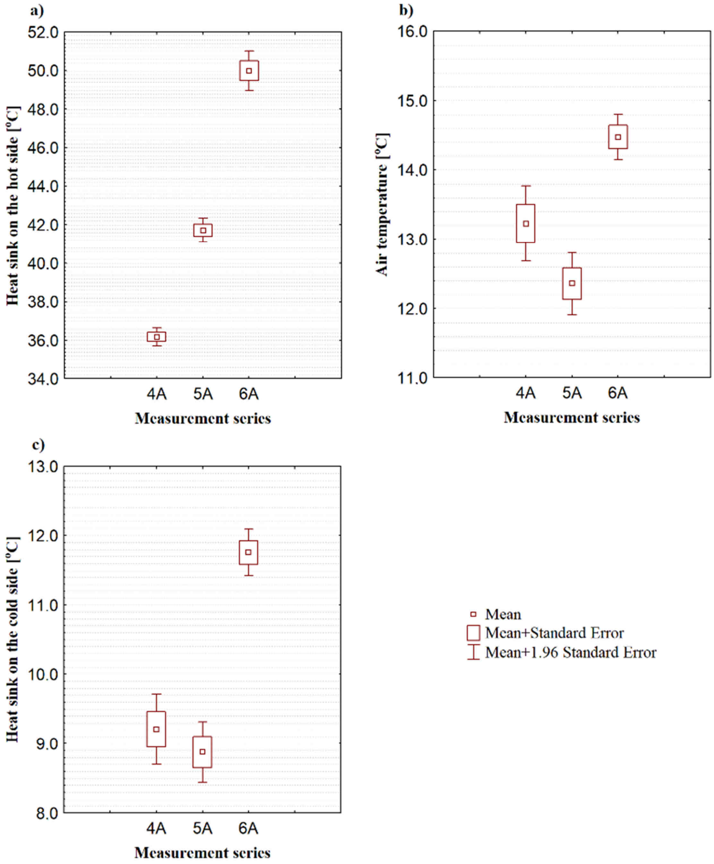

Fig. 4. Statistics of the measured temperatures: a) on the heat sink on the hot side, b) air inside the experimental room, c) on the heat sink on the cold side

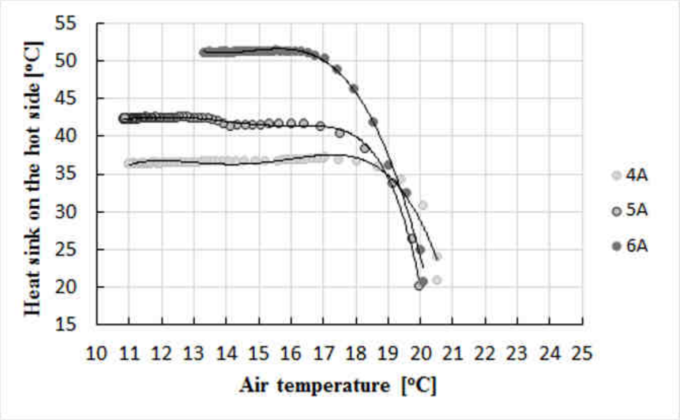

Fig. 5. Relation between the temperature on the heat sink on the hot side of the module and the air temperature inside the experimental room

The performed statistical analyses of correlation for the obtained results of temperature measurements at the selected locations (see Fig. 2) of laboratory system and for the given values of the applied current showed strong statistically significant correlations of measured temperatures, including coefficients of correlation R = 0.938-0.982 for hot sides of TE module, R = 0.963-0.967 for the experimental room and R = 0.993-0.997 for the cold side of TE module, respectively. The results of statistical analyses based on the Kruskal-Wallis one-way analysis of variance showed in most of the tested cases statistically significant differences, for level of significance p = 0.05, among temperatures observed for the applied currents (4, 5, 6 A) in the tested locations (see Fig. 3). Only for temperatures measured on the cold side of the TE module for 4 and 5 A currents, the observed differences were not statistically significant.

Conclusions

In this paper the operation of a thermoelectric cooling system installed in the laboratory experimental room and powered by three applied values of current was studied. Based on the conducted experimental analysis, the following conclusions can be formulated:

- The observed cooling effects under the laboratory conditions depends on the value of current applied to the TE module. The best results of cooling efficiency were achieved for current 5 A for which the decrease in temperature inside the experimental from 20 to 10.9 °C was noted. In most of the studied cases the observed differences in measured temperature for various values of applied currents were statistically significant.
- In general, application of the tested TE module and the proposed heat exchanger under the laboratory conditions allowed to decrease temperature inside the experimental room by approx. 6.7-9.1 °C.
- The higher values of current applied to the TE module the higher temperature value on the hot side were obtained, as a result of the Joule's heat. This heat can be reused for

a certain purpose such as preliminary heating of domestic water. Thus, the overall system efficiency could be improved.

Acknowledgments

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References

[1] Zhao D, Tan G. Appl Thermal Eng. 2014;66:14-24. DOI: 10.1016/j.applthermaleng.2014.01.074.

[2] Champier D. Energy Conv Manage. 2017;140:167-181. DOI: 10.1016/j.enconman.2017.02.070.

[3] Bansal P, Vineyard E, Abdelaziz O. Int J Sust Built Environ. 2012;1;85-101. DOI: 10.1016/j.ijsbe.2012.07.003.

[4] Enescu D, Virjoghe EO. Renew Sust Energ Rev. 2014;38:903-916. DOI: 10.1016/j.rser.2014.07.045.

[5] Goldsmid HJ. The Thermoelectric and Related Effects. In Introduction to Thermoelectricity. Heidelberg: Springer; 2016. ISBN 978-3-662-49255-0

[6] Gołębiowska J, Żelazna A, Zioło P. Proc. SPIE 10445. DOI: 10.1117/12.2281042.

[7] Zhang M, Tian Y, Xie H, Wu Z, Wang Y. Int J Heat Mass Transfer. 2019;137;1183-1190. DOI: 10.1016/j.ijheatmasstransfer.2019.03.155.

[8] Chen WH, Liao CY, Hung CI. Appl Energy. 2012;89:464-473. DOI: 10.1016/j.apenergy.2011.08.022.

[9] Kim HS, Liu W, Ren Z. J Appl Phys. 2015;118(11):115103. DOI: 10.1063/1.4930869.

[10] Novak V, Podobnik B, Možina J. Appl Thermal Eng. 2013;57:99-106. DOI: 10.1016/j.applthermaleng.2013.03.060.

[11] Liu D, Zhao FY, Yang HX, Tang GF. Energy. 2015;83:29-36. DOI: 10.1016/j.energy.2015.01.098.

[12] Siecker J, Kusakana K, Numbi BP. Renew Sust Energy Rev. 2017;79:192-203. DOI: 10.1016/j.rser.2017.05.053.

[13] Twaha S, Zhu J, Yan Y, Li B. Renew Sust Energy Rev. 2016;65:698-726. DOI: 10.1016/j.rser.2016.07.034.

[14] Liu Z, Zhang L, Gong G. Energy Convers Manage. 2014;87:559-565. DOI: 10.1016/j.enconman.2014.07.05.

[15] Liu ZB, Zhang L, Gong G, Luo Y, Meng F. Energy Buildings. 2015;86:619-625. DOI: 10.1016/j.enbuild.2014.10.053.

[16] Wiriyasart S, Naphon P, Hommalee C. Case Studies Thermal Eng. 2019;13;100369. DOI: 10.1016/j.csite.2018.100369.

[17] Matuska T, Zmrhal V, Zavrel V, Slanina P. IOP Conf. Ser.: Earth Environ. Sci. 2019;290;012080. DOI: 10.1088/1755-1315/290/1/012080.

[18] Liu ZB, Li W, Zhang L, Wu Z, Luo Y. Energy Buildings. 2019;186:46-55. DOI: 10.1016/j.enbuild.2019.01.017.

DZIAŁANIE UKŁADU Z OGNIWEM TERMOELEKTRYCZNYM ZASTOSOWANYM DO CHŁODZENIA KOMORY BADAWCZEJ

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Abstrakt: Ogniwa termoelektryczne, zwane również ogniwami Peltiera, mogą być wykorzystywane do procesu chłodzenia w różnych rozwiązaniach konfiguracyjnych. Ogniwa termoelektryczne działają jak pompa ciepła - dostarczenie energii do ogniwa powoduje, że energią z jego jeden strony, zwanej stroną zimną, jest pobierana i transportowana na drugą, zwaną stroną gorącą. Efekty działania ogniwa Peltiera zależą od zastosowanych wymienników ciepła oraz od natężenia prądu zasilającego ogniowo. W pracy przedstawiono działanie wybranego ogniwa termoelektrycznego wykorzystanego do chłodzenia komory badawczej o kubaturze 0,125 m^3. Po obu stronach ogniwa zastosowano wymienniki składające się z radiatorów aluminiowych i wentylatorów w celu usprawnienia procesu wymiany ciepła. Podczas trwania badań śledzono zmianę temperatury wewnątrz komory badawczej, na radiatorze po stronie zimnej oraz na radiatorze po stronie gorącej ogniwa termoelektrycznego przy zmiennym natężeniu prądu zasilającego wynoszącym od 4 do 8 A. Najlepsze efekty chłodzenia otrzymano przy natężeniach prądu 4 i 5 A. W tych przypadkach udało się obniżyć temperaturę wewnątrz komory badawczej o ok. 8 °C. W przypadku zasilenia ogniwa prądem o natężeniu 8 A doszło do ogrzania komory badawczej o ponad 5 °C.

Słowa kluczowe: ogniwa termoelektryczne, moduły Peltiera, efekt chłodzenia