Filin S. O., *doc. tech. Sciences*
Zakrzewski Bogusław, *doc. tech. Sciences*

Filin S.O.

West-Pomeranian Technological University,
Szczecin, 17, al.Piastow, Szczecin,
70-310, Poland, *e-mail: sergiy.filin@zut.edu.pl*

Zakrzewski B.

EXPERIMENTAL STUDIES OF THE INFLUENCE OF THE FAN AND MODULE OPERATING MODE ON THE CHARACTERISTICS OF THERMOELECTRIC BEVERAGE COOLER

Using a beverage cooler as an example, the dependence of the temperature T_c of the chamber (container) of the cooler on the supply voltage U_f of the fan on the hot side of the unit was experimentally determined for various values of the supply voltage U_m. of the module. The correct choice of the supply voltage U_f of this fan allows not only to reduce the power consumption of the entire product, but also to reduce the temperature of the cooler chamber by 1-6 ° C, which automatically leads to an increase in its speed. When the supply voltage of the thermoelectric module U_m changes in the range from 0.3-0.4 to 0.75-0.8 of the nominal value, a minimum of the T_c (U_f) function is observed. Bibl. 14, Fig. 4, Tabl. 2.

Key words: thermoelectric beverage cooler, cooling depth, fan, supply voltage, experimental studies.

Introduction

A number of previous author's publications [1-5] were devoted to the design of thermoelectric beverage coolers in original containers, i.e. in metal cans and plastic bottles. As part of the research, the market of modern household and car thermoelectric beverage coolers was analyzed in terms of their cooling rate. It has been shown that the speed of these devices does not satisfy the needs of consumers. The use of "wet" contact is proposed to increase the speed of coolers, and the efficiency of this solution is shown both by calculation and experimentally. This work is a continuation of previous research. The next phase is devoted to the analysis of the influence of various factors on the main technical characteristics of the mentioned coolers.

As can be seen from Table 1, the choice of the most important technical characteristics of a thermoelectric device depends on its purpose and mode of operation (permanent or occasional work). For refrigerators and minibars, such characteristics are the average power consumption *P*, the daily or annual energy consumption E and the temperature difference ΔT created. For beverage coolers, these are the cooling rate V, also called the speed, and the cooling depth ΔT.

Table 1

Qualitative analysis of the degree of influence of the selected design and operational factors on the most important technical characteristics of household thermoelectric devices

Group of products Factor	Mini bar coolers	Beverage coolers	Ice makers	Air conditioners
Operation (operating mode)	Permanent	Occasional	Occasional	Long-term, seasonal
The most important characteristics	P or E, ΔT	V, ΔT, $	G, $	E or P, ΔT, $
Efficiency of thermoelectric material and modules	++	++	++	++
General layout, form	+	+	++	+
Heat transfer conditions on radiators (heat exchangers)	++	++	+	++
The effectiveness of thermal insulation of the chamber (containers, ice molds)	++	+	0	0
Efficiency of AC/DC power supply	+	+	+	+
Temperature control method	++	+	0	+
Cost-effectiveness of auxiliary equipment (chamber lighting, automation, fans, etc.)	+	+	0	++

where: E – energy consumption, [kWh/day]; P – power consumption, [W]; ΔT – created temperature difference (for refrigerator), cooling depth (for beverage cooler), [^{o}C]; operating temperature range (for air-conditioner); V – cooling rate, [^{o}C/h]; G – productivity, [kg/h]; $ – price [$].
++ – strong influence, + – moderate influence, 0 – there is no or negligible influence.

Table 1 shows the factors that influence the characteristics of the selected types of devices. The experience of creating and operating household thermoelectric products shows that improving their characteristics is not limited only to increasing the efficiency of thermoelectric materials. The total influence of other factors is comparable, and in some cases exceeds the influence of the effectiveness of materials. Among these other factors, the conditions of heat exchange on the radiators on both sides of the thermoelectric module or modules should be highlighted. Temperatures of overcooling the cold radiator and overheating the hot radiator have a direct effect on the cooling capacity and energy efficiency of a thermoelectric module [6,7]. Therefore, the conditions of heat transfer on the radiators are highlighted as a factor of strong influence.

Brief analysis of literature, purpose and object of research

The efficiency of heat exchange on both sides of the thermoelectric module depends on the fan performance, which, in turn, depends on its supply voltage. Therefore, the main variable parameter was the fan supply voltage. It should be remembered that in household appliances powered from a 220-230 *V* AC mains through a rectifier, it is easy to implement an independent power supply for the module and the fan. The study of the influence of the supply voltage of the fan placed in the refrigerator or display cabinet on the average temperature in the chamber was carried out quite a long time ago and is described in [8-10]. At the same time, the study of the influence of the fan operating mode on the hot side of the module on the temperature characteristics of a thermoelectric product is of even greater interest. In addition to [10], where such studies were carried out in a very limited scope, such experimental work has not yet been carried out. Recent works devoted to experimental studies of thermoelectric coolers [11-14] also do not address these issues. The aim of the study was to fill this gap.

A thermoelectric beverage cooler with "wet contact" of the TSSN-0.5 type, presented in Fig. 1 and described in detail in [1-5], was chosen as the object of research. The cooler is designed for cooling drinks in metal cans with a volume of 0.33 and 0.5 liters and in plastic bottles of the same volume. The cooler contains one thermoelectric module of the MT2-1.6-127 type, whose cold side is in contact with the bottom of a thermally insulated cylindrical container made of aluminum. The hot side of the module is connected to a radiator, which is blown by an Everflow type R128025DM fan with a nominal supply voltage of 12V DC. An independent power supply for the module and the fan is provided in the investigated object. The aluminum radiator located under the fan plays the role of a stand and a distancer and practically does not participate in heat exchange.

a)

b)

Fig.1. Prototype of a household thermoelectric beverage cooler TSSN-0.5 [3]: a – general view, b – testing moment.

Research method, brief description of the experimental bench and test procedure

To achieve this goal, the way of doing experimental research was chosen. The tests were carried out in the laboratory of thermoelectric cooling of the Department of Air Conditioning and Refrigerated Transport of the West Pomeranian University of Technology in Szczecin in the period 2020-2021.

A simplified diagram of the experimental bench and the installation diagram of temperature sensors are shown in Fig. 2. To measure temperatures, resistance temperature sensors TSM-100 were used, which are part of the IT-10 measuring complex. The measurement results were recorded with a frequency of 10 seconds using the Channel 2.0 software. The module and the fan were powered from an external two-channel power supply of the M10-DP-305E type with independent control of the output electrical parameters. After the chamber temperature stabilized at the next value of the fan supply voltage, the power supply switched to the next voltage value at a constant value of the supply voltage of the thermoelectric module. Typical dynamics of the chamber temperature change during the tests is shown in Fig. 3.

The tests were carried out at a laboratory room temperature of 22 + 1 ºC, maintained with a split-type household air conditioner. The tests were carried out for two operating modes of the cooler: with an empty chamber (container) and with a drink in a 0.33 liter can (Fig. 1 b).

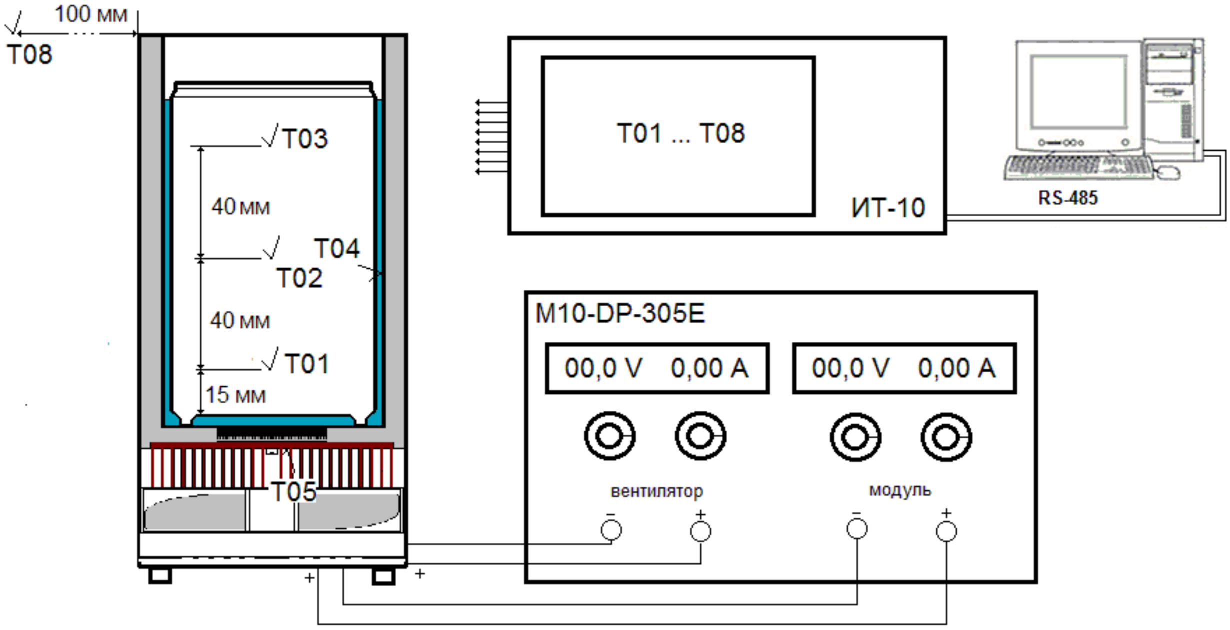

Fig.2. Block diagram of the experimental bench with indication of the thermocouple installation locations.

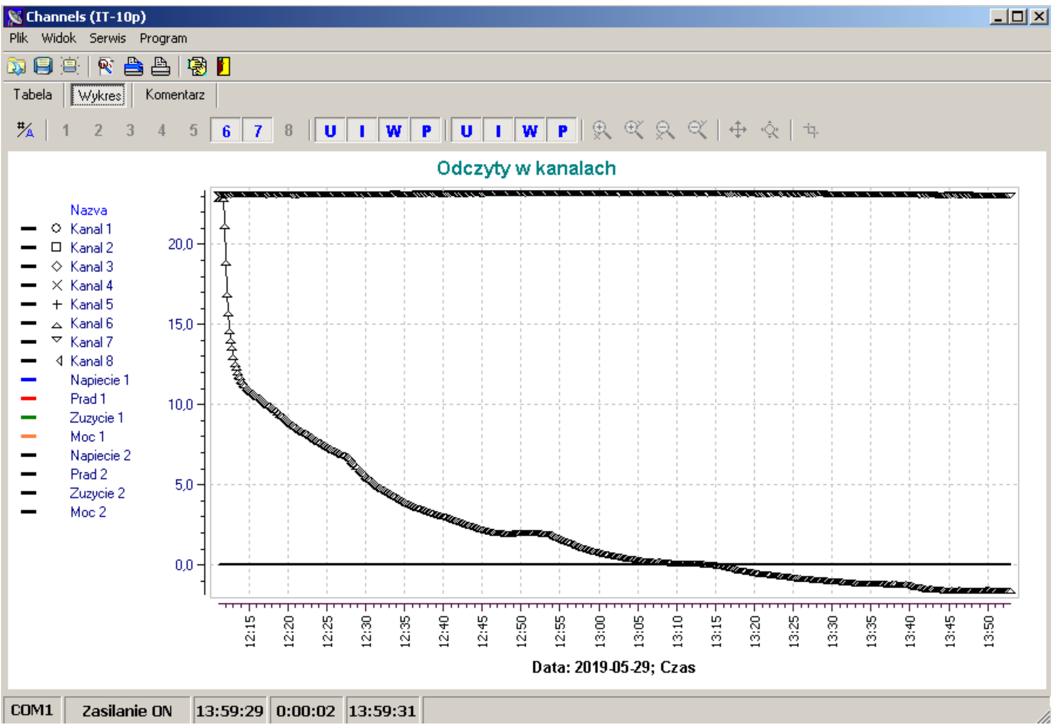

Fig.3. The dynamics of change in the temperature of the chamber T_c during tests at U_m = 10V.

Test results and their analysis

The test results of a cooler with a metal can in synthetic form are presented in Table 2. The fan supply voltage was regulated in the range from 6 to 14 V, which follows from many years of experience in operating this type of axial fans. They remain operational when the supply voltage changes in the range from 5 to 15 volts. In the experiment, we limited ourselves to the range of 6-14 volts for the following reasons. At a voltage below 6V, problems arise with the start of the fan, although with a gradual decrease in voltage from 6 to 5V, it continues to work at low speeds. Voltage over 14V is associated with increased power consumption and increased noise.

<u>*Table 2*</u>

Results of testing the thermoelectric cooler at variable values of supply voltage of module U_m and fan U_w

Temperatures °C →	T_c			T_h			ΔT		
Voltages U_m→ ↓U_f	6V	8V	10V	6V	8V	10V	6V	8V	10V
6V	5.1	5.9	6.7	34.3	39.3	50.2	29.2	33.4	43.5
8V	4.3	4.3	2.0	32.2	35.9	45.2	27.9	31.6	43.2
10V	4.1	4.3	0.1	31.0	34.7	42.3	26.9	30.4	42.2
12V	4.4	4.3	-1.0	30.3	32.7	40.4	25.9	28.4	41.4
14V	4.6	5.4	-1.3	29.6	31.9	39.4	25.0	26.5	40.4

The range of voltage variations of the module was narrowed to the limits from 6 to 10V, which followed from previous experiments [3]. Changes in the temperature of the hot radiator T_h fully corresponded to our expectations: for each constant value of the module supply U_m (6, 8, and 10 V), with an increase in the fan supply voltage U_f, the temperature of the hot radiator T_h decreased, and this decrease was more significant at higher values of U_m. The situation looked completely different on the cold side, where the temperature of the wall of the container (chamber), in which the can with the drink was located, was measured. Here, the minimum values of the container temperature T_c were observed at the supply voltage U_f = 10V at the module supply voltages of 6V and 8V, and at U_m = 8V the minimum was blurred. At U_m = 10V, a monotonic decrease in the temperature T_c with an increase in U_f was observed (Fig. 4).

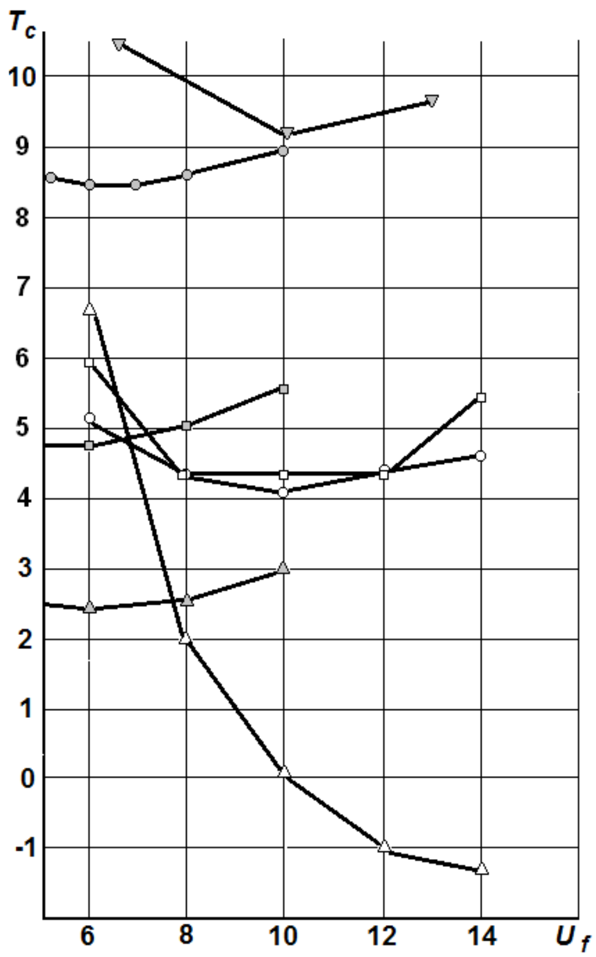

Fig.4. Dependence of the container (chamber) temperature T_c on the supply voltage of fan U_f Installed on the hot side of the module at different values of its supply voltage, namely: ○ - U_m = 6V; □ - U_m = 8V; △ - U_m = 10V; *the rest of the graphs and symbols relate to the comparison of results with the data of other studies, and are explained in the text.*

Fig.4 also shows a comparison of the results obtained with the results of known, earlier works. The symbol ▽ denotes the dependence of the temperature in the chamber of a 103^{-l} thermoelectric refrigeration display case on the supply voltage of the fans on the hot side of the unit [10], and the symbols ○ □ △ show the dependence of the temperature in the chamber of the thermoelectric beverage cooler with a volume of 13.5 l on the supply voltage of the fan in the chamber, i.e. on the cold side of the unit [8]. The first of the above dependences (▽) has minimum near U_f = 10V. This value coincides with the results obtained in the present work. Does this mean a universal recommendation for choosing U_f?

With regard to the fact that $U_{f(opt)}$ is influenced not only by the module supply voltage, but also by the design of the hot heat exchanger, fan type, temperature control method and a number of other factors, it is too early to make a final conclusion about the optimal value of $U_{f(opt)}$. At the same time, we can confidently draw a qualitative conclusion: there is an optimal fan supply voltage on the hot side from the point of view of temperature reduction in the chamber T_c, and it is less than the nominal fan supply voltage. Another, not so obvious, but important conclusion: the larger the heat exchange surface the hot radiator has, the lower the optimal fan supply voltage will be. In stationary thermoelectric refrigerators and other devices in which weight reduction is not a priority task, the use of a radiator with a larger surface leads to an increase in the cost of the refrigerator within 5-6 %. In this case, a corresponding decrease in the fan supply voltage means a 2% to 4% reduction in power consumption. The result of the feasibility study depends on the frequency (intensity) of using the refrigerator. If a stationary refrigerator or beverage cooler is used 24 hours a day for more than 3 months a year for a minimum of 5 years, operating cost savings are prioritized over investment cost savings.

A similar dependence of T_c on U_f, but this time on the cold side of the unit, also demonstrates a minimum for various values of U_m (○ $-U_m$ = 6V; □ $-U_m$ = 8V; △ $-U_m$ = 10V), which corresponds to the minimum value of the fan supply voltage, i.e. 6V. The physical meaning of this behavior of the function T_c (U_f) is as follows. In going from natural to forced convection, which is observed at U_f = 5-6 V, there is an abrupt decrease in the average temperature in the refrigerator chamber. However, a further increase in the fan supply voltage, which corresponds to an increase in the air circulation rate in the chamber, leads to the fact that the total thermal resistance to heat transfer on the chamber walls (taking into account the leakage of the door insulation) decreases faster than the resistance on the cold heat sink. As a result, an increase in the heat flux through the chamber insulation prevails in the balance of heat fluxes.

Conclusions

The studies carried out have once again shown the importance of coordinating the operating modes of the module (modules) and fans used in the units of various thermoelectric products. Using a beverage cooler as an example, the dependence of the temperature T_c of the chamber (container) of the cooler on the supply voltage U_f of the fan on the hot side of the unit was experimentally determined for various values of the supply voltage of the module U_m. The correct choice of the supply voltage U_f of this fan allows not only to reduce the power consumption of the entire product, but also to reduce the temperature of the cooler chamber by 1-6 ° C, which automatically leads to an increase in its speed. When the supply voltage of the thermoelectric module U_m changes in the range from 0.3-0.4 to 0.75-0.8 of the nominal value, a minimum of the T_c (U_f) function is observed.

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Філін С.О. *докт. техн. наук*
Закшевський Богуслав, *докт. техн. наук*

Західнопоморський технологічний університет у Щецині,
алея Піаст 17, Щецін, 70-310, Польща;
e-mail: *sergiy.filin@zut.edu.pl*

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ВПЛИВУ РЕЖИМУ РОБОТИ ВЕНТИЛЯТОРА І МОДУЛЯ НА ХАРАКТЕРИСТИКИ ТЕРМОЕЛЕКТРИЧНОГО ОХОЛОДЖУВАЧА НАПОЇВ

На прикладі охолоджувача напоїв експериментально визначена залежність температури T_c камери (ємності) охолоджувача від напруги живлення U_f вентилятора на гарячій стороні агрегату при різних значеннях напруги живлення модуля U_m. Правильний вибір напруги живлення U_f цього вентилятора дозволяє не лише знизити споживану потужність виробу в цілому, а й на 1-6°C знизити температуру камери охолоджувача, що автоматично призводить до підвищення його продуктивності. При зміні напруги живлення термоелектричного модуля U_m в діапазоні від 0,3-0,4 до 0,75-0,8 номінального значення спостерігається мінімум функції T_c (U_f). Бібл. 14, рис. 4, табл. 2.

Ключові слова: термоелектричний охолоджувач напоїв, глибина охолодження, вентилятор, напруга живлення, експериментальні дослідження

Филин С.О. *докт. техн. наук*
Закшевский Богуслав, *докт. техн. наук*

Западнопоморський технологический
университет у Щецине
алея Пиастив 17, Щецин, 70-310, Польша;
e-mail: sergiy.filin@zut.edu.pl

ЕКСПЕРЫМЕНТАЛЬНЫЕ ИСЛЕДОВАНИЯ ВЛЕЯНИЯ РЕЖИМА РОБОТЫ ВЕНТИЛЯТОРА И МОДУЛЯ НА ХАРАКТЕРИСТИКИ ТЕРМОЭЛЕКТРИЧЕСКОГО ОХЛАДИТЕЛЯ НАПИТКОВ

На примере охладителя напитков экспериментально определена зависимость температуры T_c камеры (емкости) охладителя от напряжения питания U_f вентилятора на горячей стороне агрегату при различных значениях напряжения питания модуля U_m. Правильный вібор напряжения питания U_f этого вентилятора позволяет не только снизить потребляемую мощность всего изделия, но и на 1-6ºC снизить температуру камеры охладителя, что автоматически приводит к повешению его производности. При изменении напряжения питания термоэлектрического модуля U_m в диапазоне від 0,3-0,4 до 0,75-0,8 номинального значения наблюдается минимум функции T_c (U_f). Библ. 14, рис. 4, табл. 2.

Ключевые слова: термоэлектрический охладитель напитков, глубина охлаждения, вентилятор, напряжение питания, экспериментальные исследования.

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