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ECONOMICAL TRANSPORT THERMOELECTRIC REFRIGERATORS WITH TWO-LEVEL TEMPERATURE CONTROL: THE EXPERIENCE OF CREATION AND TEST RESULTS

The article describes the experience of creating Transport Thermoelectric Refrigerators (TTER) on the basis of household cabinets of thermoelectric refrigerators by Ravanson Company with a useful volume of 48 liters. Also the results of comparative tests of the basic model and the two new TTER samples with different types of thermoelectric modules are presented. Using two-level temperature control has significantly improved the energy performance of refrigerators, which enables their long-term operation with the power supply from the vehicle's battery without the risk of rapid discharge.

Key words: thermoelectric refrigerator, temperature control, electrical power, energy saving.

Introduction

The main and global objective of technical progress in the early XXI century, beyond question, is energy efficiency increase. The reduction of energy consumption of thermoelectric refrigerators is not only in this tideway, but also is prerequisite for competitive ability of thermoelectric products in the world market, primarily with respect to compressor analogs.

At Department of Air Conditioning and Refrigerated Transport of West Pomeranian University of Technology in Szczecin, investigations of mostly experimental nature have been pursued for more than 15 years with the aim of improving the energy parameters of various-purpose thermoelectric refrigerators. The above improvement is a consequence of selected approach to design of stationary thermoelectric coolers and displays, namely optimization of refrigeration unit design and its power supply circuit, combined with a respective method of temperature control in the refrigerator chamber. New samples of refrigerators offer not only lower power requirement, but also reduced daily energy consumption due to maximum increase of operation time in energy-saving mode. The results of these efforts are regularly published in the "Journal of Thermoelectricity". Several monographs in Polish and Russian have appeared. Within recent two years, investigations have been pursued with a view to apply the above approach to transport refrigerators powered from direct current mains 12 V. Preliminary results of these works were reported to XV International Forum on Thermoelectricity [1]. The work phase represented in this paper was performed in the framework of a project of "Inkubator innowacyjnosci" program, which is supported by Ministry of Science and Higher Education of Poland and aimed at promoting new technologies [2].

Purpose, objects and methods of investigation

The purpose of the project was to create and test new designs of low-cost transport thermoelectric refrigerators (hereinafter – TTER) powered from direct current mains 12 V or from a battery using the principle of two-level temperature control. This idea has been earlier tested on stationary thermoelectric refrigerators and displays with chamber volume from 40 to 100 liters and power supply from alternating current mains 230 V. Transport refrigerators of such volume find application on yachts, in railway cars, tourist buses, mobile homes and truck trailers, auto shops, mobile coffee houses and in summer cottages. In the absence of external electrical grid or diesel-generator, continuous operation of refrigerator from a battery can result in its discharging. Therefore, a reduction of TTER power requirement at least by several watts is of principal significance.

Since the above TTER are only custom-built, and the budget of and terms of the project were very limited, it was decided to take as the basic model a retail household thermoelectric refrigerator Ravanson LK-48 with chamber volume 48 liters. Its technical specifications are represented in Table 1. Four refrigerators were purchased, of which two were intended for comparative tests and the other two – for adaptation to transport version. When creating two samples of new products, from the basic model only thermally insulated cabinets were used where new units were placed according to principal diagrams described in [1]. The models of new refrigerators with abbreviation ChTT-48 were different only in the type of thermoelectric modules used: MT2-2.5-127 (ChTT-48-1) and MT2-2.0-127 (ChTT-48-2). The general view of the refrigerators is represented in Fig. 1.

Table 1

Technical specifications of thermoelectric refrigerator Ravanson LK-48
(according to manufacturing data)

Parameters	Measuring unit	Value
1. Temperature range in the chamber	ºC	5…12
2. Total chamber volume	dm^3	48
3. Supply voltage	V	~230
4. Current frequency	Hz	50
5. Overall dimensions (width, depth, height)	mm	480 × 460 × 840
6. Power consumption (at t_{amb} = 32ºC)	W	70
7. Weight	kg	11.6
8. Daily energy consumption	kW h/24h	0.8*

* – manufacturer does not indicate the conditions when this parameter was measured.

Fig. 1. Refrigerators ChTT-48 in the process of laboratory test.

The research program provides for comparative testing of new samples and basic model, as well as individual testing of new samples at different ambient temperatures and thermostat settings. Apart from he tests performed in department laboratory, part of them were performed in COCH certified Refrigeration Centre in Krakow, in particular, tests at ambient temperature t_{amb} = 32ºC and tests with a loaded chamber. The main measured values were the energy and dynamic characteristics, such as: chamber temperature, power requirement, daily energy consumption, time and conditions of transition into energy-saving mode.

A correct comparison of parameters of refrigerators with different supply voltage, kind of current and different temperature control principle was assured by the following techniques:

- according to the results of preliminary tests, the electrical efficiency of power supply LK-48 and its dependence on temperature and voltage on the module was determined, which made it possible to a sufficient degree of precision to recalculate the refrigerator power requirement from ~230V supply mains to = 12 V;

- with regard to the differences in temperatures in the chamber of compared models, use was made of practically approved parameter of specific power consumption, proposed in [3].

An experimental bench described in [1] was modernized, in particular, supplemented with a battery of HZY-EV12-100 type and electronic meters of direct current power consumption FRER C15UCL with the division value 1 Wh. The meter C15UCL (Fig. 2) also makes possible recording of current strength, power consumption actual values and a number of other parameters, computer data recording. Using of this rather rare and precise instrument makes it possible to detect even a small difference in the energy consumption of objects with power requirement 10...20 W without the need for performing many days, and even many weeks of testing.

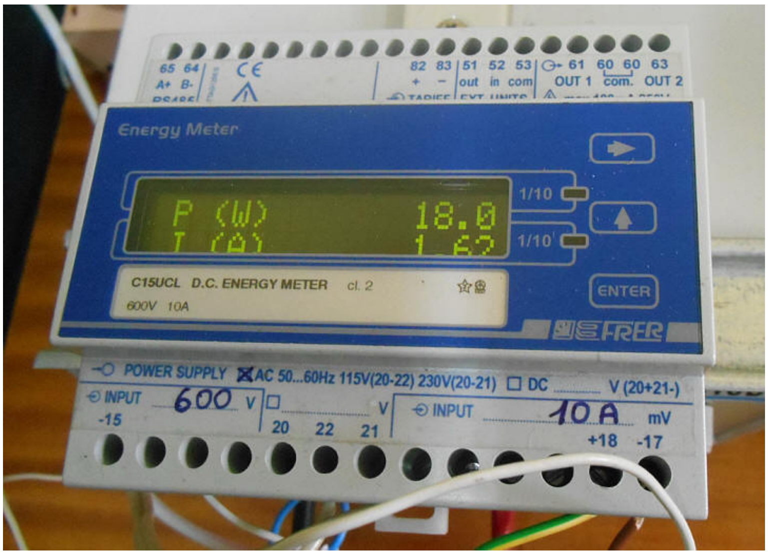

Fig. 2. Direct current energy parameters meter FRER C15UCL.

Results of testing refrigerator LK-48

Analysis of design and operating principle of refrigerator LK-48 was performed by "reverse engineering" method. Restoration of refrigerator electric circuit diagram according to its wiring diagram has shown that the refrigerator employs not a manometric, but electronic temperature controller wherein temperatures sensor (thermal resistor) is switched into a bridge leg. Temperature controller is the inseparable part of supply circuit with a high-frequency voltage converter, pulse-width modulation and feedback. In other words, proportional temperature control was used as the most efficient method known [1]. Though, in principle, one can also use proportional regulation at refrigerator supply from direct current mains, nevertheless technical decisions used in LK-48 do not provide this opportunity.

When testing LK-48, measurements were performed of the electrical parameters both in alternating current and direct current circuits (in thermoelectric module circuit), as well as of energy parameters. Tables 2 and 3 represent extracts from testing protocols of this refrigerator at the ambient temperature 23ºC for two thermostat settings "4" (middle) and "1" (min)[1]. Parameters at the moment beginning transition to energy-saving mode are shown against the grey background.

Table 2

Results of testing thermoelectric refrigerator Ravanson LK-48
with empty chamber at ambient temperature 23ºC and thermostat setting "4"

Time		Alternating current	Direct current			Temperatures	
absolute [h:min]	relative [min]	Power requirement *P*, [~W]	*V*, [V]	*A*, [A]	*P*, [=W]	Average in chamber, [ºC]	of hot heat sink, [ºC]
11:50	0	75.9	12.0	5.,20	62.4 (65.4)	21.5	21.5
12:05	15	64.4	12.0	4.38	52.6	16.1	40.0
12:20	30	64.3	12.0	4.37	52.4	12.8	39.8
13:20	90	64.1	12.0	4.37	52.4	7.0	38.8
13:37	107	64.0	12.0	4.37	52.4	6.5	38.7
13:40	110	63.9	11.9	4.36	51.9 (54.9)	6.4	38.7
13:55	125	61.6	11.6	4.27	49.5	6.0	38.6
14:10	140	56.8	10.9	4.10	44.8	5.7	37.8
15:03	193	51.7	10.4	3.89	40.4	5.7	36.8
16:00	250	51.7	10.5	3.89	40.8	5.7	37.0
16:05	255	51.8	10.5	3.90	40.9 (43.4)	5.7	37.1

Table 3

Results of testing thermoelectric refrigerator Ravanson LK-48
with empty chamber at ambient temperature 23ºC and thermostat setting "1"

Time		Alternating current	Direct current			Temperature	
absolute [h:min]	Relative [min]	Power consumption *P*, [~W]	*V*, [V]	*A*, [A]	*P*, [=W]	Average in chamber, [ºC]	Hot heat sink, [ºC]
14:05	0	78.9	12.0	5;12	61.4 (64.4)	22.0	23.2
14:20	15	63.9	12.0	4.36	52.3	16.3	40.4
14:35	30	63.6	12.0	4.35	52.2	12.8	40.2
14:45	40	63.6	12.0	4.35	52.2	11.1	39.5
14:49	44	62.8	11.9	4.33	51.5 (54.5)	10.7	39.5
15:00	55	48.7	10.1	3.76	38.0	9.5	37.0
15:20	75	28.8	7.5	2.75	20.6	9.1	33,6
15:40	95	23.5	6.6	2.40	15.8	9.3	32.4
16:18	133	25.4	6.9	2.53	17.4 (19.1)	9.5	33.0

[1] Setting scale of refrigerator thermostats, irrespective of their operating principle, is from "1", which corresponds to maximum, i.e. higher temperature in the chamber, to "7", which, in turn, corresponds to minimum temperature. Accordingly, setting "4" is middle. It is generally recommended by the manufacturer of refrigerators for everyday use.

At the ambient temperature of 23ºC and thermostat setting “4”, a transition to energy-saving operation mode starts in 110 minutes after switching (Table 1), when the temperature in the chamber falls to 6.4ºC and lasts nearly 1.5 hours. The transition lies in a smooth reduction of module supply voltage with the respective reduction of current and power consumption. During this time the temperature in the chamber falls to 5.7ºC and is stabilized at this level, and the power consumed from the rid is reduced from 63.9 to 51.8 W. With regard to energy consumption of the fans (the values in brackets in *P* [=W]) column, and taking into account that their supply voltage is synchronized with modules supply voltage, a reduction of power consumption in direct current circuit 12 V is, respectively, from 54.9 to 43.4 W.

At the same ambient temperature and thermostat setting “1”, a transition to energy-saving operating mode starts 44 minutes after switching, when the temperature in the chamber falls to 10.7ºC, and lasts nearly an hour. During this time the temperature in the chamber is reduced to 9.3..9.5ºC and is stabilized at this level, whereas power consumption from the grid is reduced from 62.8 to 25.4 W. Accordingly, reduction of power consumption in direct current circuit is from 12 V is from 54.5 to 19.1 W.

At thermostat setting “4”, transition to energy-saving mode is observed at ambient temperature not above 24ºC, and at thermostat setting “1” – not above 28ºC. In so doing, the refrigerator energy consumption should be determined in conformity with standard EN ISO 8561:1995 + A1:1997 at ambient temperature 25ºC and mean thermostat setting, i.e. in position ‘”4”. It means that under these conditions refrigerator LK-48 does not pass into energy-saving mode. The tests have shown that its power requirement (on conversion to direct current) is in this case 53.16 W, and daily energy consumption, accordingly, made 1.276 kWh. The value 0.8 kWh indicated by the manufacturer in passport specifications of the refrigerator refers to setting “1”. We have more than once mentioned in our previous publications that concealment of conditions of determination of such important parameter as daily energy consumption can disorient the buyer concerning its economical operation.

Some results of comparative tests and their analysis

Apart from structural differences, the basic difference of a new transport refrigerator ChTT-48 from known analogs with temperature controller is that its energy consumption and temperature in the chamber in energy-saving mode depend only on ambient temperature and do not depend on thermostat setting. Thermostat setting has impact only on the refrigerator’s dynamic characteristics. The time from switching to transition to energy-saving mode can vary from 15 minutes at setting “1”, i.e. for maximum temperature in the chamber, to 1...2 hours at settings “4”– “7”. Time of temperature stabilization in the chamber on switching to energy-saving mode, on the contrary, will be less at thermostat setting for lower temperatures. On the whole, a new refrigerator has much better dynamic characteristics than the counterpart LK-48, especially with regard to the fact that transition to energy-saving mode and back occurs immediately. This peculiarity also has a positive effect on the daily energy consumption.

In the process of testing, the modules ChTT-48 were powered from a direct current source D3010 which provides for two operating modes: voltage stabilization and current regulation (restriction). On switching of refrigerator ChTT-48-1, power source for 15...30 seconds worked in current restriction mode, following which it automatically passed to 12.0 V voltage stabilization mode. When testing the model ChTT-48-2, the source remained in current restriction mode up to transition to energy-saving mode, and supply voltage in operating mode was 10.5... 10.6 V.

Table 4

Some results of comparative test of refrigerators LK-48 and ChTT-48
with empty chamber at ambient temperature 23ºC and thermostat setting "4"

Parameters	LK-48	ChTT-48-1	ChTT-48-2
Maximal created temperature difference, K	17.8	19.8	22.0
Temperature difference created in energy-saving mode, K - setting "4" - setting "1"	 17.3 13.9	 14.5	 14.9
Power requirement, W - in working mode - in energy-saving mode setting "4" setting "1"	 64.1 (53.16*) 52.1 (41.0*) 25.4 (19.1*)	 61.0 16.0	 50.0 (73.0**) 19.0
Parameter of specific power requirement P_{spec} for energy-saving mode, W/dm^{3}K - setting "4" - setting "1"	 0.063 (0.049*) 0.038 (0.029*)	 0.023	 0.0266

* – on conversion to power supply from direct current circuit 12 V.
** – for battery power supply.

As is seen from Table 4, new refrigerator models, especially ChTT-48-1, which employs lower-power modules, outperforms in the energy parameters the counterpart, even with a conventional conversion of its characteristics to power supply from direct current circuit. In this model, a parameter of power requirement 16 W is achieved, which is more than 3 W less than the respective parameter LK-48 in the most economy mode of its operation. In practice, besides energy saving it may mean increased rime of refrigerator operation from the battery without recharging from several hours to several days as a function of operating conditions.

It is true that foe the improvement of energy figures one had to "pay" with a slight (2 K on the average) average temperature increase in the chamber in energy-saving mode, but, on the other hand, new models offer a higher refrigerating capacity and larger maximum temperature difference created in operating mode.

Conclusion

The paper presents certain most important results. The tests of refrigerators are underway. On their completion and processing of the results, full data will be published. However, even at this stage one can assert that the adopted technical decisions gave the expected results. The major of them is confirmation of feasibility and efficiency of a two-level temperature control in TTER by switching cooling unit feed from a parallel to series circuit and back.

Apart from improving the energy parameters, the operating temperature range of thermoelectric refrigerators has been expanded by about 2 – 3ºC, making possible a transition to energy-saving operation mode. This data needs verification and refinement, which is to be done in the nearest future.

Patent applications have been filed to the Polish and European patent agencies for technical decisions used in TTER [4, 5].

Fig. 3. Presentation of ChTT-48 refrigerator at EuroGastro Exhibition 2015 in Warsaw.

One of the models ChTT-48 in March 2015 was exhibited at EuroGastro exhibition in Warsaw (Fig. 3) where it aroused great interest of potentail end buyers.

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