Experimental Investigations of a Thermoelectric Heat Exchanger with Heat Bridges

O.V. Evdulov
Department of theoretical and electrical engineering
Daghestan State Technical University
Makhachkala, Russia
ole-ole-ole@rambler.ru

I.Sh. Mispakhov
Department of theoretical and electrical engineering
Daghestan State Technical University
Makhachkala, Russia
igram.mispahov@yandex.ru

I.A. Gabitov
Department of theoretical and electrical engineering
Daghestan State Technical University
Makhachkala, Russia
gabitovia@mail.ru

R.A-M. Magomadov
Department of electrical engineering and electric drive
Groznyy State Petroleum Technological University n.a. M. D. Millionshikov
Groznyy, Russia
Rustmag_80@mail.ru

U.I. Abdulkhakimov
Department of electrical engineering and electric drive
Groznyy State Petroleum Technological University n.a. M. D. Millionshikov
Groznyy, Russia
pobeda66-66@mail.ru

R.Sh. Kazumov
Department of theoretical and electrical engineering
Daghestan State Technical University
Makhachkala, Russia
kazumov.rev@yandex.ru

***Abstract*—The article deals with the construction of a thermoelectric heat exchanger with heat bridges. A test stand and a full-scale test procedure of this device have been developed, which allow determining temperature change dependencies in control points on current level in thermoelectric modules, charge coefficient, material of heat bridges. The conducted studies proved practicability of heat bridges in thermoelectric heat exchangers. It has been found that charge coefficient influences energy characteristics of the device, material of heat bridges influences device operating efficiency little. Divergence of the experiment results with previous device mathematical simulation has been determined. It does not exceed 9 %.**

Keywords—thermoelectric heat exchanger; thermoelectric module; heat bridge; a test stand; measurement

I. INTRODUCTION

At the current stage of science and technology development research of devices for intensive heat transmission from high heat flux sources, creation of new high performance cooling and thermal stabilization systems, which meet specific requirements, design of heat exchangers with improved characteristics are actual. It is caused by the saturation of the global market with new devices with improved operational capacities and high speed operation, but with increased value of specific thermal overloads, that influences their operational reliability.

The most perspective trend in this case is application of semiconducting thermoelectric converters, providing construction of energy-conserving, small-sized refrigerators and temperature stabilizers with wide functional capabilities for keeping the specified heating rate. [1-3]. Theory and application of such devices are described in these works [4-9]. In the above mentioned works various parameters of devices operating in different modes are described, energy efficiency of their application have been determined. The main emphasis has been done on the study of thermos physical processes at a constant temperature on seals of thermal energy converters.

But there are many applications of thermal electric devices, where temperature variation of heat-transfer agents along the surface of a thermoelectric module takes place (TEM), absorbing and generating heat. There are different types of heat exchangers: coolers and heaters of fluid streams, air-coolers air conditioners, and so on, that is, all devices where coolant circulation is along TEM seals. Despite significant progress in thermos electrical technology, there are few works on such devices, little theoretical grounds for their operation, effective modes of their operation and fields of their application are not specified.

The study of specially designed thermoelectric heat exchangers with improved energy characteristics, their optimization, sizing, and fields of application are of special interest. It is caused by lack of studies in this field together with acute necessity of developing high-efficient heat exchangers with improved characteristics. These circumstances determine topicality of the present study.

The purpose of the work is experimental testing of thermoelectric heat exchanger with heat bridges of improved energy, size and reliability characteristics.

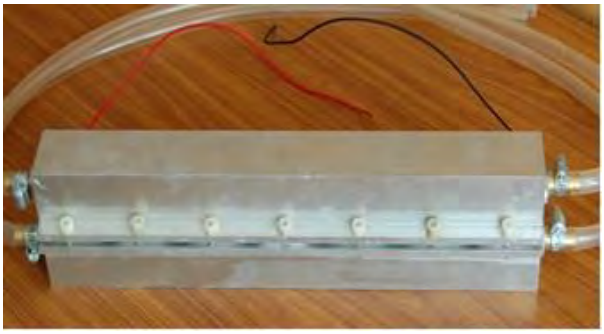

Fig.1. The layout of the thermoelectric heat exchanger with heat bridges

II. Description of the Experimental Device

To study the heat exchanger we designed a test stand whose scheme is given in Fig. 2.

A heat exchanger 1 is connected both to the circulation loop of a cold- and heat carrier and a controlled source of direct current. Water is used as a cooling and heating carrier. 2. Ultra thermostats 3 and 4 keep the predetermined temperatures of cold- and heat carriers on the input of the heat exchanger with the precision 0.1 °C and provide their circulation. Losses on cold- and heat carriers are regulated with faucets on corresponding ultra-thermostats.

Current temperatures are recorded with a complex IRTM 2402/M3 5, which is switched to PC 6 and may be connected simultaneously to 24 temperature sensors.

The object of the experimental investigation was a thermo electric heat exchanger, shown in Fig. 1. It consists of two steel tubes with the internal diameter 7 mm and length 250 mm, which carried heat and cooling agents. The outside tube surface is tetrahedron 20×20 mm in size. TEM are between the tubes (10 units). Standard modules of TB-71-1.4-1.8 type, produced by Kryotherm (Saint-Petersburg) [10]. The space between TEMs with different density of spacing was filled with solid-metal heat bridges made of copper, aluminum, steel.

TEM and heat bridges connected electrically in series via heat conducting paste SWTF were clammed between two tubes.

Copper constantan thermocouples are set on the side edges along the tubes t_1 - t_{10}, whose supporting seals are thermos stabilized at 0 °C in a cryogenic storage dewar.

Lengthwise temperature distribution curves were received at different points of the heat exchanger: with different coefficients of filling space between modules with heat bridges; different currents flowing through TEMs; different materials for heat bridges.

All the experiments were conducted at predetermined constant temperatures and consumption of cold- and heat carriers at the inlets of the structure. For this the heat exchanger was firstly filled with only semiconducting TEMs, 10 units (100% TEM charging, charging coefficient is ξ=1).

The prescribed temperatures and consumption of cold and heat carriers at the inlets were kept with the help of ultra-thermostats. After stabilizing ultra-thermostats modes (in 15-20 minutes) circular monitoring of thermocouples with further displaying of temperature data on the PC screen was done with the measuring complex. Simultaneously the heat exchanger was connected to the dc power supply, whose gauge set a desired supply current value.

Charge coefficient was changed in the following way: after the device assembly a part of TEMs was switched off, the rest of the modules were distributed along the tube at a steady pace, heat bridges from corresponding material were set between TEMs, whose total area is equal to total area of distant modules. Heat bridges of different types were produced for this. For example for 80% charging (ξ=0.8), two modules were pulled out of 10 TEM, and 2 heat bridges were set, each of them was equal to 1/4 of the module area.

Before the experiment reliability of electrical and heat contacts was checked, certain temperature values were determined, which were kept during the whole experiment.

A number experiments were conducted on the test stand which allow judging about the heat exchanger characteristics.

The main goal of the heat exchanger experimental testing was determining temperature dependencies in control points mentioned above on TEM current supply, charge coefficient, and heat bridges material.

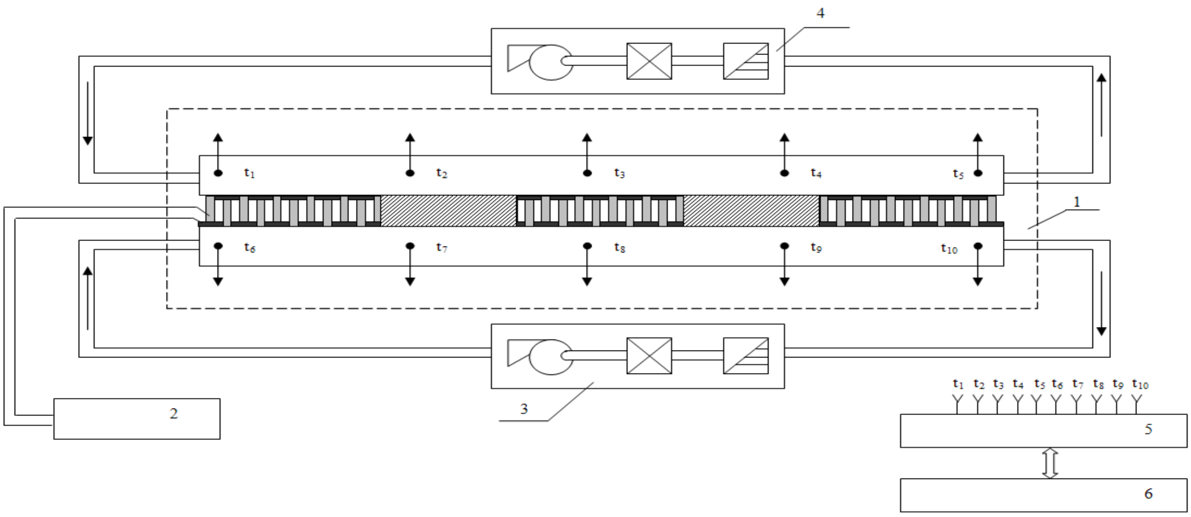

Fig. 2. Principle scheme of the test stand

III. Experimental Results

Fig. 3 shows experimental results (points) of the heat exchanger at stationary operating condition at different TEMs charging coefficients and for comparing the results of theoretical calculations (a solid line). During calculations prescribed rates for thermos-physical properties of semi-conducting substance and TEM characteristics used in the construction, branches' geometrical parameters, and electrical and heat resistant contact values were used. Tubes' heat capacity was not taken into account.

Fig. 3 shows that calculation results [11] and experimental data correspond to each other. Maximal quantitative deviations in theoretical calculations with experimental results not more than 9 % were at the initial p of the pipeline that can be considered satisfying. As the figure shows with charge coefficient increase the temperature distribution changes curves change sharply that is the heat exchanger works more efficiently.

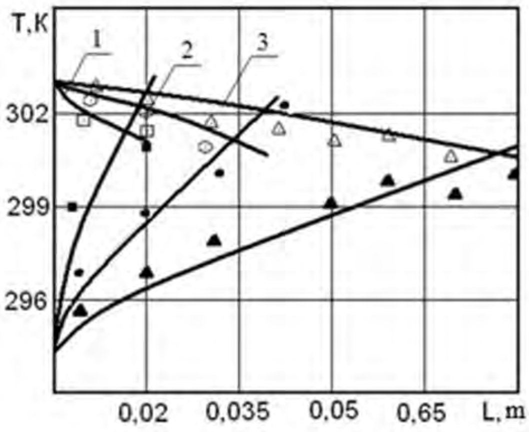

Fig. 3. Experimental and theoretical temperature dependencies of heat-carriers on the outlet of the heat exchanger on the length at different charging coefficients (1 - ξ=1,0; 2 - ξ=0,5; 3 - ξ=0,2; TEM feed current is 1,8 A)

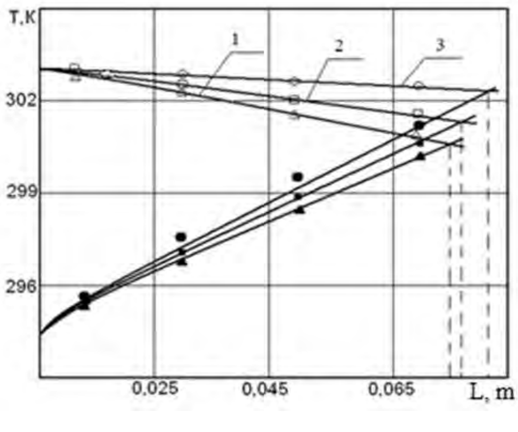

Fig.4. Experimental and theoretical temperature dependencies of heat carriers on the outlet of the heat exchanger on heat bridges materials (1 - copper, 2 - aluminum, 3 - steel; feed current TEM 1.8 A)

Fig. 4 shows temperature distribution curves along the heat exchanger with the charge coefficient equal ξ=0.2, for heat bridges from different metals: copper, aluminum and steel.

These data evidence that heat exchanger efficiency does not depend on heat bridges material that is proved by the results of the numerical experiment. But using copper heat bridges is more effective which is caused by its heat conductivity coefficient.

Fig. 5 shows dependence of thermobattery length, composed of TEM during device functioning in intensive mode on supply current at charge coefficient ξ=0.5 for copper heat bridges. As measurement results show current supply increase decreases the area of the heat exchanger where the battery operates in the mode of heat exchange intensification. For example, current increase by 0.5 A for these conditions the specified length decreases by 1.8 cm.

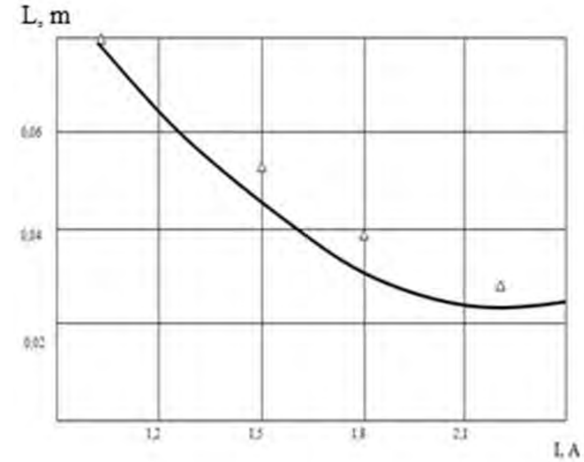

Fig. 5. Dependence of TEB overall length in the heat exchanger on supply current (ξ=0.5, heat bridge material is copper)

Fig. 6 shows experimental dependencies of temperature changes in the point 1.5 cm far from the input into the heat exchanger on time. According to graphs data temperature stabilizes at the input of the heat exchanger in 27 min after switching TEM.

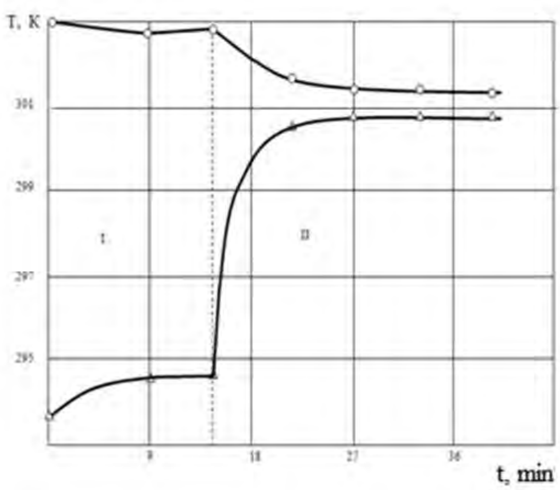

Fig.6. Heat carrier temperature dependence on time without (area I) and with (area II) SDB (ξ=0.8, L=0.015 m; I=1.8 A, heat bridge material is copper)

On the whole experiment results prove that application of heat bridges in the construction of thermoelectric heat exchanger is rational.

IV. CONCLUSION

Basing on the results of the experiment we can draw the following conclusions:

1. Basing on the literature review of heat exchange intensification methods, and heat exchanger constructions it has been determined that to intensify the heat exchange between two streams of heat carriers it is rational to apply thermoelectric energy converters.

2. Principle of constructing thermoelectric heat exchange devices has been suggested. It combines possibility to transfer heat via highly conductive heat bridge and heat exchange intensification during application of TEM.

3. A test stand has been created and measuring procedure have been developed, which allow determining temperature change dependencies in control points on TEM current supply magnitude, charge coefficient, heat bridge material.

4. Experimental studies of the heat exchanger are conducted, which prove the practicability of heat bridges application. It has been determined that energy characteristics of the device are influenced by charge coefficient value, heat bridges material has little influence on the device efficiency.

5. Temperature equalizing period of heat- and cold carriers has been determined at the outlet of the heat exchanger which is equal to 27 min.

6. Calculation results deviation of the device and experiment is satisfactory and is not more than 9 %.

References

[1] L.I. Anatychuk, “Thermoelectricity. Thermoelectric energy converters,” Kiev, Chernovtsy: Termoelectricity institute, 2003.

[2] L.P. Bulat, “Applied studies and developments thermoelectric cooling in Russia,” Refrigerating engineering, No. 7, 2009.

[3] Ssennoga Twaha, Jie Zhu, Yuying An, and Bo Li, “A comprehensive review of thermoelectric technology: Materials, applications, modelling and performance improvement,” Renewable and sustainable energy reviews, No. 65, 2016.

[4] L.I. Anatychuk, “Electricity circit technology,” Lectures of IX Interstate seminar “Thermoelectric materials and their application,” Saint-Petersburg, 2004.

[5] L.I. Anatychuk, “On physical models of thermoconverters,” Thermoelectricity, No. 1, 2003.

[6] B.Ye.-Sh. Malkovich, “Thermoelectric modules based on telluride bismuth alloys,” Lectures of IX Interstate seminar “Thermoelectric materials and their application,” Saint-Petersburg, 2008.

[7] S.O. Filin and B. Zakshevskiy, “Current state, future developments and production of stationary thermoelectric refrigirators,” Thermal electricity, No. 2, 2008.

[8] V.A. Semenuk and A.V. Antonenko, “Relibilization of TE coolers,” Thermal electricity, No. 4, 2007.

[9] T.A. Ismailov and O.V. Yevdulov, “Heat exchange process simulating in a thermoelectric device for cooling electronics,” Journal of Instrument Engineering, No. 7, 2002.

[10] Foundation for Assistance for Internet Technologies and Infrastructure Development, retrieved from: http://www.kryotherm.spb.ru

[11] O.V. Evdulov and D.K. Kadirova, “Thermoelectric intensifier of a continuous heat transmission,” Thermal electricity, No. 6, pp. 82-86, 2016.

[12] T.A. Ismailov, O.V. Yevdulov, M.A. Khazamova, and R.A-M. Magomadov, “Mathematical simulation of the thermoelectric system for local heat impact on a human hand,” Thermal electricity, No. 1, pp. 77-86, 2014.