RESEARCH ON THE ENERGY CHARACTERISTICS OF PERMEABLE PLANAR THERMOELEMENT

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- *Results of research on the design of permeable planar thermoelement used for cooling and heating of gas and liquid fluxes are presented. Procedure of experimental determination of thermoelement parameters in air cooling and heating mode is described. The values of energy characteristics of thermoelement based on Bi-Te-Se-Sb semiconductor materials are presented. The results obtained indicate the possibility of providing air cooling and heating mode at the level of 5 – 25°C with the energy efficiency exceeding 6 – 16% the capabilities of conventional thermoelements.*

Introduction

The recent trend of improving energy conversion efficiency is the use of more general physical models of thermoelements where heat exchange with the heat source and heat sink takes place not only on the junctions like in conventional thermoelements, but also in the bulk of the legs material [1]. The embodiments of such models are permeable thermoelements where in the legs materials along passage of electrical current there are channels (pores) for pumping of heat carrier [2-4]. Controlling heat exchange conditions (heat carrier rate, heat exchange intensity, etc.) in combination with the distribution of physical effects in the legs material, one can affect energy conversion efficiency for the purpose of its improvement.

The first theoretical studies of such thermoelements for cooling gas and liquid fluxes showed [5-7] good prospects of their use due to possibility of increasing coefficient of performance by 30 – 40%. This expands considerably the potential of practical use of direct machine-free thermoelectric cooling method which is known [1, 8] to be characterized by simple design, high precision of temperature mode control, ecological cleanliness, performance reliability, etc.

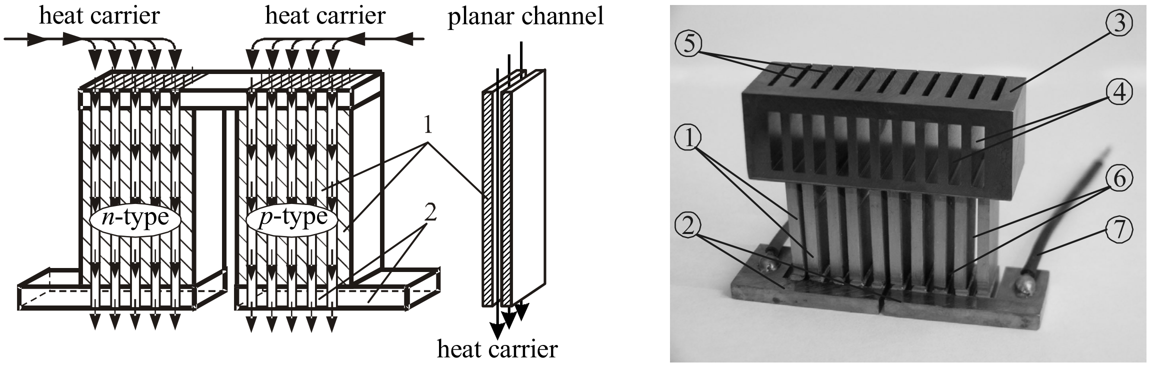
However, creation and practical implementation of permeable thermoelements is related to material research and technological problems caused by arrangement of heat carrier heat exchange in the bulk of the legs. This stimulates a search for simpler variants of physical models of converters with the internal heat exchange. A variant of implementation of the internal heat exchange are permeable planar thermoelements [7] where each leg is composed of a certain number of plates that are in space relationship. Intervals between the plates form channels for pumping of heat carrier (liquid or gas).

The purpose of this work is to study permeable planar thermoelement based on *Bi-Te-Se-Sb* semiconductor materials and to determine its energy characteristics in air cooling and heating mode.

Permeable thermoelement design

Fig. 1 shows a physical model of permeable planar cooling thermoelement (Fig. 1 *a*) and the thermoelement design (Fig. 1 *b*). The thermoelement is composed of *n*- and *p*-type legs based on *Bi-Te-Se-Sb* materials made of plates 1 coated with anti-diffusion nickel layers; electrically connecting copper stripes 2 that connect leg plates 1 along the cold surface; copper heat exchanger 3 coated with anti-diffusion nickel layer and connecting leg plates along the thermoelement hot side. Heat exchanger 3 has a system of channels 4 for pumping of heat carrier that removes heat from the thermoelement hot side and a system of channels 5 of heat carrier that must be cooled. Said channels together with channels 6 formed by thermoelement leg plates 1 and electrically connecting stripes 2 create a system of end-to-end channels of permeable thermoelement for pumping of heat carrier that must be cooled.

Passage of electrical current of respective polarity by means of electrical leads 7 through legs 1 due to joint action of the Peltier and Joule effects causes heat-up of upper heat exchanger 3 and cooling of electrically connecting stripes 2. Passage of liquid heat carrier that must be cooled or air through a system of end-to-end channels 5, 6 results in its cooling due to heat exchange with the lateral, cooler side of legs 1.



a) *b)*

Fig. 1. Physical model and design of permeable thermoelement.

Methods and results of experimental investigations

Investigations of permeable thermoelement were performed on a stand schematically shown in Fig. 2. Wind tunnel 2 and a fan 3 were used for creation of air flux through thermoelement 1. Thermal insulation from the ambient is ensured by polyvinyl chloride housing 4 and foam plastic 5. Ammeter 6 and voltmeter 7 are used to measure the thermoelement supply parameters. Temperature control of thermoelement hot junctions is provided by liquid thermostat 8. Air flux control is afforded by a change in fan 3 rotation velocity by means of supply unit 9. Thermoelement inlet air temperature and the hot and cold thermoelement junction temperatures are determined by differential thermocouples 10 – 12, respectively. Thermocouple signals are output to voltmeter 14 through switch 13. Free junctions 15 of measuring thermocouples 10 – 12 are placed into null thermostat 16, such as a vacuum flask with a mixture of water and ice. Thermoelement outlet air temperature and velocity is determined by sensor 17 of anemometer 18.

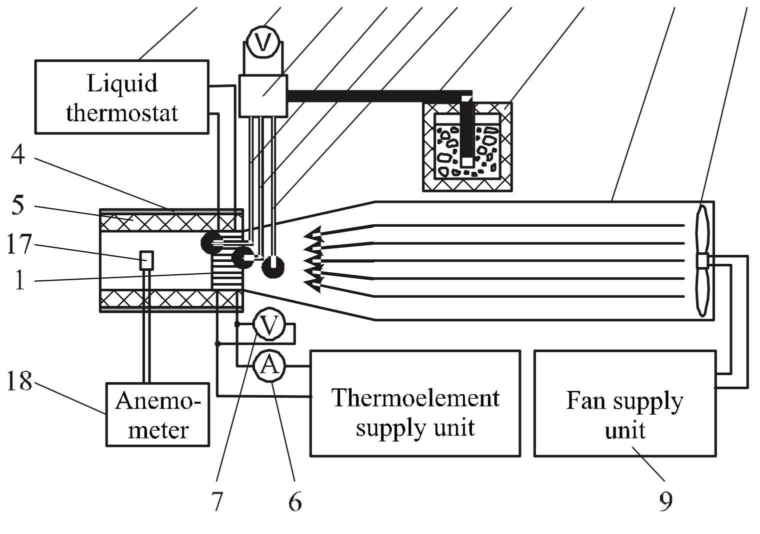


Fig. 2. Schematic of testing stand for permeable thermoelements.

Water thermostat 8 is used to keep the hot junctions of thermoelements at the level of ambient temperature T_{amb}°C. The value of current *I* through thermoelements which is measured by ammeter 6 is controlled by supply unit. Air velocity through thermoelement is set by means of fan supply unit and controlled according to readings of anemometer 18.

Thermoelement presented in Fig. 1 *b* is made of thermoelectric extruded materials based on *Bi-Te-Se-Sb* with the average parameter values: thermoEMF $\alpha \approx 192$ V/K, electrical conductivity $\sigma \approx 985$ $\text{Ohm}^{1}\text{cm}^{-1}$. Thermoelements are made of *n*- and *p*-type leg plates 2.4 × 10 × 10 mm, and 5 such thermoelements are connected electrically in series into a thermopile. The cross-section area of such thermopile was 6 cm^2, with the area of leg material 2.4 cm^2 and the cross-section area between leg plates 3.6 cm^2, that is, the value of permeability was 0.6.

As a result of measurements, characteristics of a permeable thermopile were obtained for different air flux velocities in cooling mode (Fig. 3) and heating mode (Fig. 4).

Fig. 3 shows dependences of temperature difference between the "hot" and "cold" thermoelement junctions ΔT, air cooling depth Δt, cooling capacity Q_c and the value of coefficient of performance ε versus the value of electrical current *I*. The data is given for different air velocities (index 1 corresponds to air velocity 0.1 m/s; 2 – 0.4 m/s; 3 – 1 m/s) under conditions when air temperature at the inlet to channels was 30°C.

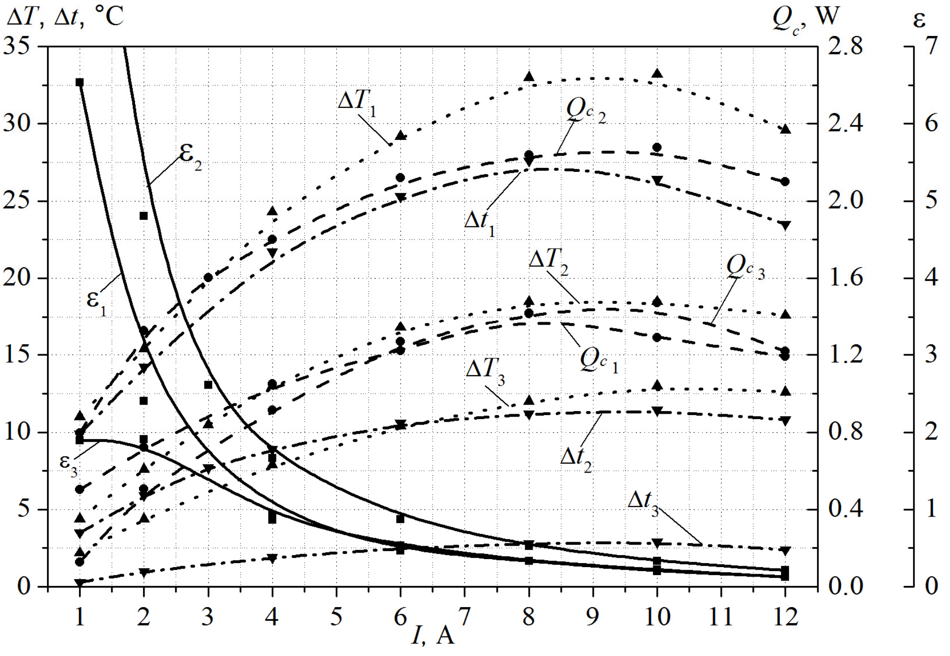


Fig. 3. Characteristics of thermoelement in cooling mode.

As is evident from the data, the regions of maximum air cooling depth correspond to maximum cooling capacity values for all air velocity values.

As supply current decreases, coefficient of performance *ε* grows and acquires maximum values at such minimum supply current *I* which still ensures the necessary air cooling temperature. Therefore, in maximum energy efficiency mode, permeable thermoelement should be used with a minimum supply current, as specified by theory in [2, 7].

Maximum cooling capacity Q_c of thermoelement was obtained at air velocity 0.4 m/s, and maximum air cooling depth is carried into effect at air velocity 0.1 m/s. The data obtained imply that there is optimal air velocity whereby cooling capacity Q_c and coefficient of performance *ε* will be the greatest. Thus, at a velocity of 0.4 m/s and current 4A the air is cooled by 9°C with thermodynamic efficiency $\varepsilon = 1.8$, which exceeds the value of coefficient of performance for conventional thermoelements by 6 – 12%.

Fig. 4 shows the results of permeable thermoelement operation in heating mode. Presented here are dependences of heating coefficient μ, heating capacity Q_h, temperature difference on thermopile junctions ΔT, temperature difference in the air Δt on thermopile supply current I for different air flow rates (index 1 corresponds to air velocity 0.1 m/s; 2 – 0.4 m/s; 3 – 1 m/s). At air velocity 0.4 m/s and current 3A the values obtained were as follows: $Q_h = 7.5$ W, $\mu = 11$, $\Delta T = 29$°C, $\Delta t = 24$°C. The obtained μ values exceed the respective values for conventional thermoelements by 8 – 16%.

There is good agreement between experimental data and theoretical calculations performed by the procedure described in [7] with account of interconnection resistances, heat spreaders and heat exchange system on the hot junctions of thermoelement. The optimal operating conditions of permeable thermoelement can be determined on the basis of computer design programs developed at the Institute of Thermoelectricity.

The obtained cooling and heating capacity values can be improved through use of liquid heat carrier in the channels of permeable planar thermoelement. In such a case the intensity of heat exchange between heat carrier and leg material is substantially improved owing to which the energy figures are also increased.

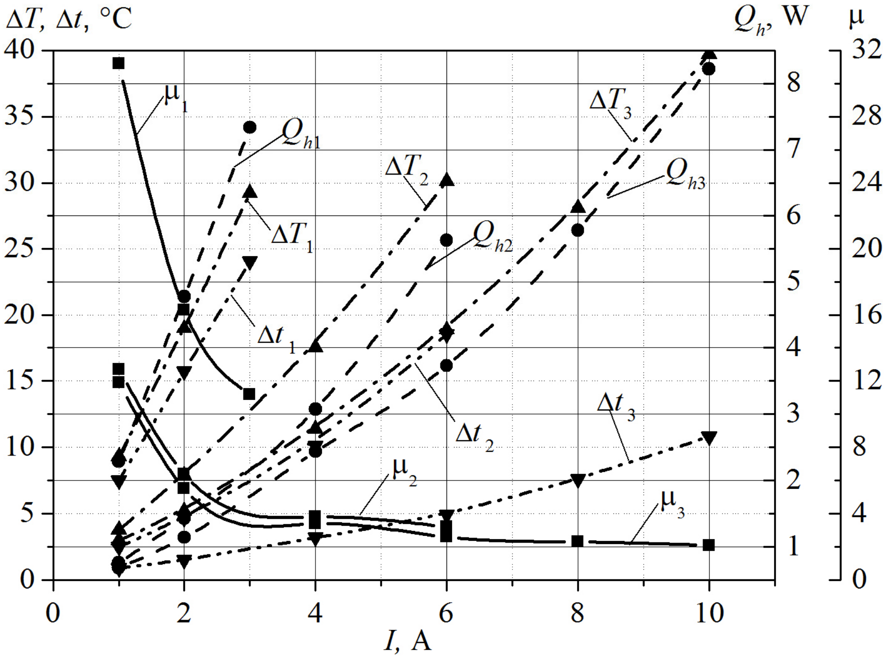


Fig. 4. Characteristics of thermoelement in heating mode.

The depth of heat carrier cooling can be increased through use of staged schemes [9], which for permeable thermoelements are proposed in work [10]. The use of staged systems is known to expand the depth of cooling and increase coefficient of performance, particularly at boundary temperature differences [11].

Conclusions

Proposed design of permeable thermoelement based on *Bi-Te-Se-Sb* materials for air temperature control provides for air cooling and heating mode at the level of 5 – 25°C with the energy efficiency exceeding 6 – 16% the capabilities of conventional thermoelements.

This design can be improved with the aim of achieving larger cooling capacity values through use of liquid heat carriers and staging. The use of staging in permeable thermoelectric systems expands the depth of cooling and increases coefficient of performance, particularly at boundary temperature differences.

References

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