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**ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
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The influence of the plates on the effectiveness of penetrating thermoelements in the cooling regime

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This paper describes the physical model of the penetrating thermoelement with the developed surface of warmth exchange for the cooling of the air's flow. It presents the theory of the calculation and the method of the computer modeling of the temperature's and potential's allocation, the definition of the effectiveness of the energy's transformation – the cooling factor and the cooling efficiency. This work researches the 3D temperature's and materials' allocation for the material of the branches of the thermoelement based on Bi_2Te_3.

Key words: penetrating thermoelement, cooling coefficient, cooling capacity, 3d model.

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Introduction

The thermoelectrical coolers are widely used for the cooling of the electronics in different fields of usage, starting with consumer goods and ending with the designing of the spaceships. The thermoelectrical elements are widely used in cooling technics. Detailed, theoretical and experimental researches and optimization of the process of the thermoelectric cooling are conducted mainly for the stationary mode of the coolers' (modules). The results of these researches contributed to the massive industrial production of the thermoelectrical modules for the various needs [1,2].

The process of the thermoelectric cooling is not well explored nowadays. That's why specifically with the help of computer modelling we can more precisely explore it, create new thermoelectric modules and devices based on them [3,4]. We researched the model of the penetrating thermoelement with the developed system of the heat exchange for the cooling of the flow in order to find the optimal functions of the inhomogeneity of the material of the supports in combination with the search of the optimal parameters, with which the thermodynamic efficiency of the capacity of conversion will be maximal. Such thermoelectric model in perspective might be used in the future researches in this field of study, with different constructional peculiarities of the thermoelectric equipment, which, in turn, makes possible the research of the new thermoelectric materials in order to improve the conversion of energy and the cost of the thermoelectric equipment on its base.

So, the aim of the work is the verification of the influence of the geometry on the effectiveness of the penetrating element in the cooling regime.

I. The physical model of the penetrating thermoelectric cooling thermoelement

While using the material with the high penetration, the inner surface of the heat exchange might be developed. In such case the intensity of the heat exchange will highly increase and the temperature drop of the environments which exchange the heat will decrease. As the result, the beneficial temperature drop on the element will increase, what positively influences on the effectiveness of the heat transformation.

When we change the conditions of the heat exchange along the twig, we influence the volumetric distribution of the heat sources in the penetrating thermoelement. That's why we have wide opportunities to influence the energetic characteristics of the thermoelement – coefficient of efficiency or capacity and the cooling coefficient. The penetrating thermoelement consists of coherent and parallel arranged on the distance plates of the twigs N- and P- types of conduction, which are connected by switching plates. The coolant is pumped through the channel of the penetrating thermoelement. It cools by means of the heat exchange with the branch's material, where the gradient of the temperature is set up due to thermoelectric Peltier effect and the existence of the electric flow. The upper spikes are thermostatized by the heat exchangers in consequence of pumping of the coolant, the rest of the surface is adiabatically isolated. The temperature of the coolant at the entrance of the thermoelement is set.

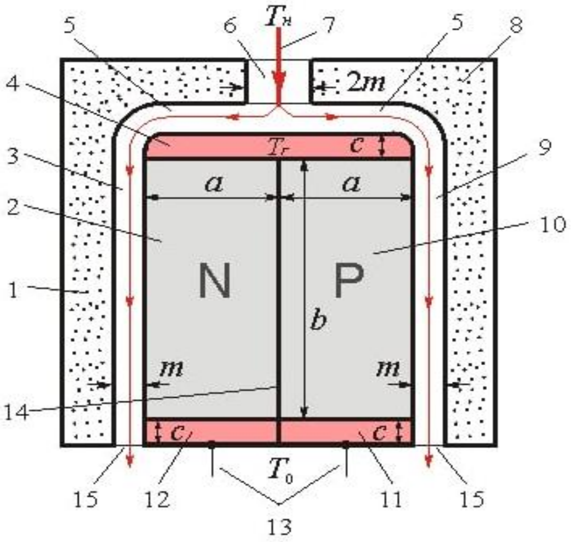

Fig.1. The physical model of the thermoelement in which the heat flows are formed because of heat exchange with the coolant, where 1 – adiabatic isolation, 2 – n-type branch, 3 – channel, 4 – commutation plate, 5 – 6 channels, 7 – coolant, 8 – adiabatic isolation, 9 – channel, 10 – branch p-type, 11 – 12 – commutation plates, 13 – electric contacts. Branches 2, 10 are embraced of the adiabatic isolation with 1, 8 and form channels 5, 6, 9. Through the channel 6 the heat carrier 7 with the temperature T_H is brought, which flows equally through channels 3, 5 and 5, 9.

The branches are made of the homogeneous material based on Bi – Te, where the temperature's dependence Z should be counted. The commutation plates are made of copper, the commutation resistance – 10^{-6} (Om • cm^2). The temperature T_0 of the lowest commutation plates is – 20°C. Branches N, P are connected with the thin layer 14, heat conductivity, electric conductivity and the thickness, which we neglect. The size of the thermoelement in the direction which is perpendicular to the picture's plane – d, magnitude d = a. Magnitude d = 0 and d = a are adiabatic isolations, which form the channels 5, 6, 9. The friction between the coolant and the adiabatic isolations 1, 8 is absent.

II. Mathematic description of the model

The existence of the heat exchange of the thermoelectric materials with the coolant negotiates the need of solutions of the problems of the temperature's allocation, electric potential and the heat's flow in the material, which are associated with the equations of motion and the heat transfer of the coolant. The movement of the coolant in the channels should be described by Navier Stokes equation and continuity equations. The equation of the heat conductivity should be explored in order to distribute temperature in the coolant. Navier Stokes equation:

$$\left.\begin{array}{c} \rho\frac{d\vec{\vartheta}}{dt} = \rho\vec{F} - \vec{\nabla}P + \mu\overrightarrow{\nabla^2}\vec{\vartheta} + \frac{1}{3}\mu\vec{\nabla}\left(div\vec{\vartheta}\right), \\ div\rho\vec{\vartheta} = 0. \end{array}\right\} \qquad (1)$$

Where the left side of the first equation (1) is the force of inertia, the first additive at the right side of the given equation – massive force, second – the effect of surface pressure forces (normal stresses), the two last additives – the effect of tangential components of surface forces (internal friction forces).

The heat exchange in the liquid is described by the equation of heat conductivity:

$$\rho C_p\left(\frac{\partial T}{\partial t} + \left(\vec{\vartheta}\vec{\nabla}\right)T\right) = -\left(\vec{\vartheta}\vec{q}\right) + \sum_{i,j}\tau_{ij}S_{ij} - \frac{T}{\rho}\frac{\partial\rho}{\partial T}\Big|_P\left(\frac{\partial\rho}{\partial T} + \left(\vec{\vartheta}\vec{\nabla}\right)P + Q \qquad (2)$$

Where ρ – density, C_p – heat capacity, T – temperature, $\vec{\vartheta}$ - liquid velocity vector, q – heat flow density, P – pressure, τ_{ij} - viscous stress tensor, η – viscosity, I – unit tensor, S_{ij} - deformation rate tensor, Q – inner heat sources.

Generalized mathematic model is based on the equation of the heat balance of the solid phase, equation of mass transfer of the gas component, equation of continuity, dynamics of filtration liquid and equation of state. Besides, it is necessary to formulate the appropriate boundary conditions. In order to solve this problem with help of computer, it is recommended to use special program, e.g. COMSOL Multiphysics.

The results of such researches where conducted for the penetrating thermoelement in 3D model and where received in the work [8] for the flow of the cooling liquid and air. This work investigates the influence of the speed of coolant's pumping and thermocouple supply voltage on the difference of temperatures and characteristics of energy penetration. It describes the optimal definition of the water's (air's) usage at the entrance of the channel and the difference of the potentials on the thermocouple, in order to achieve the maximal cooling ability during the cooldown. Optimization of the other parameters in 3D model is a great challenge.

III. Method of solving the formulated problem

Due to the diversity of applications, thermoelectric coolers can have many different configurations. With the help of COMSOL Multiphysics this package describes the basic construction of the single-stage thermoelectric cooler of different sizes with different thermocouples and other geometric characteristics. The modeled penetrating couple also can be used as the starting point for the more detailed calculations. The additional parameters of input might be extended on multi-stage thermoelectric coolers and be used in different conditions [9]. While using Peltier equation, the flow of the current from one end of thermoelectric elements to the other, creates orthogonal heat flows, which causes the temperature's drop between the plates, which gives the opportunity to calculate the productivity parameters. Afterwards this model can be used to search the best penetrating element with better productivity, equipment on its base, for the specific program or producer to optimize the construction and to provide the productivity.

In this paper is used the generalized theory of calculations of penetrating thermocouples taking into account the changes of appropriate parameters of the branch's material from the temperature and concentration of the charge's carriers and conditions of heat exchange along the height of the branch. This method of modeling of the distribution of temperature and heat's flow in 1D and 3D models of osmotic thermocouples, the improved theory of calculated osmotic thermocouples, is used to solve the tasks of multifactor optimization to achieve maximal energetic effectiveness in the viability of thermoelectric conversion. Since the penetrating couple is the element of thermocouple, so the heat exchange with the source of heat (extractor) takes place not only at the surface of spike, but also inside the branch of thermocouple [10]. In this case the extensive material becomes penetrated (with channels and pores), in order to pump the heat carrier through it (liquid or gas).

By mean of usage of highly penetrating materials, we can develop the inner surface of the heat exchange, increase the intensity of heat exchange, decrease the difference of temperature between the environments which exchange the heat. It urges to the increase of useful temperature's difference on the thermocouple, which can increase the effectivity of energy's transformation [5-7]. The volumetric distribution of the heat source (flow) in the penetrating branch of the thermocouple also might be influenced by the mean of change of the conditions of the heat transfer through the height of the branch. That's why we can influence on the energetic characteristics of the thermocouple – the cooling coefficient of the cooler or air conditioner.

IV. Calculation of the main characteristics of the penetrating thermoelement with the help of computer modeling

Thermocouple consists of two different conductors (stems), which contact with each other at one point (junction). When the temperature is set, the voltage appears between them across the connection. That's why the thermocouple is calibrated with the temperature sensor, and this can transform temperature gradients into the electric streams.

In order to estimate the characteristics of the penetrating thermoelectric thermoelement during the cooling regime using the COMSOL Multiphysics, first of all the geometry of thermoelement during the cooling regime was modeled. Let's describe more precisely geometry (fig. 2-3) of the modeled model.

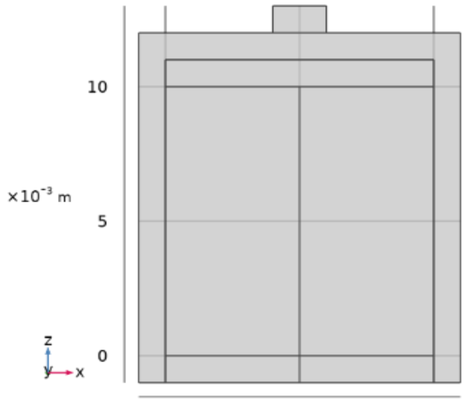

Fig. 2. One of the variations of thermoelement's geometry.

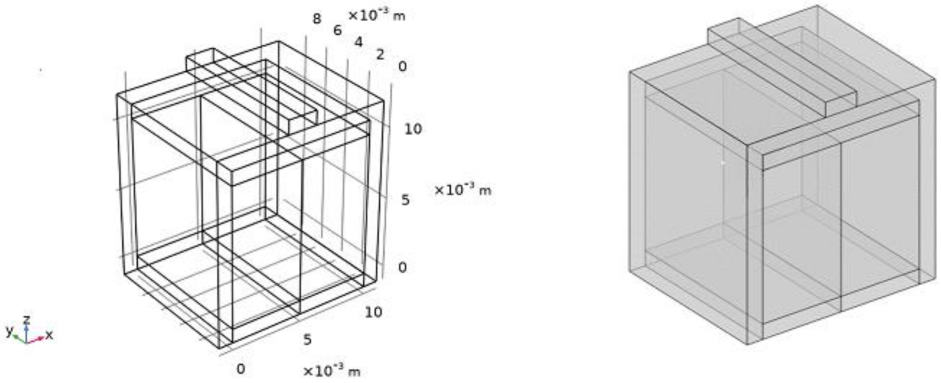

Fig. 3. Geometry of the penetrating thermoelement.

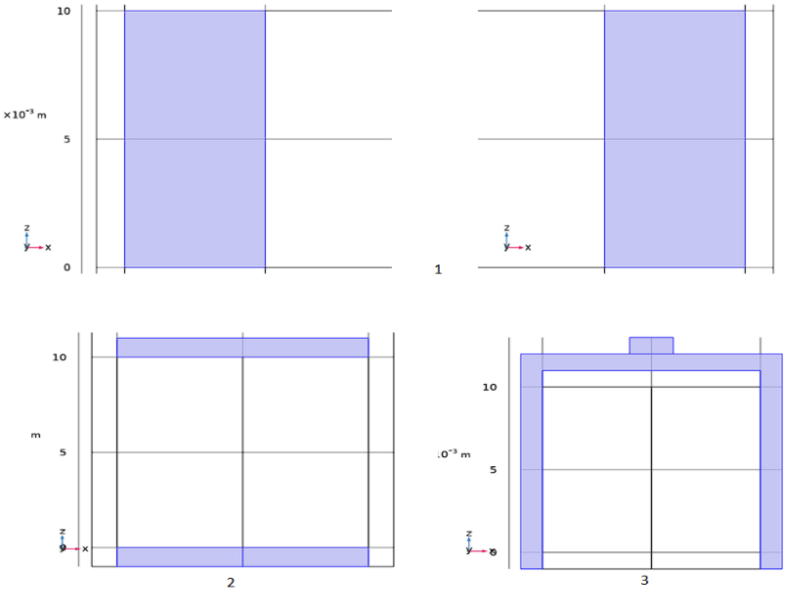

Fig. 4. Geometry of thermoelectric material – 1; commutation plates – 2; heat carrier – 3.

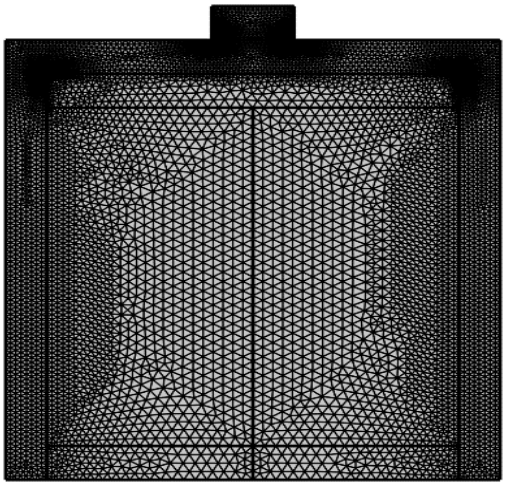

Fig. 5. Geometric grid.

Let's look at geometry of thermoelectric material with quality $Z = 0.002(\frac{1}{K})$.

On the figures (2 – 5) we can see the detailed visualization of geometry of the modeled thermoelement, where every detail of the created model is shown very precisely.

So, with the help of COMSOL Multiphysics we can observe the temperature distribution in the thermoelectric cooling module.

At the figure 6 we can clearly observe that isothermal surfaces and heat flow are shown relentlessly in the module itself and in the coolant. The distribution of speed in the coolant (fig. 7), distribution of electric potential of the penetrating thermoelement (fig. 8) and distribution of thermoelectric field of the penetrating thermoelement

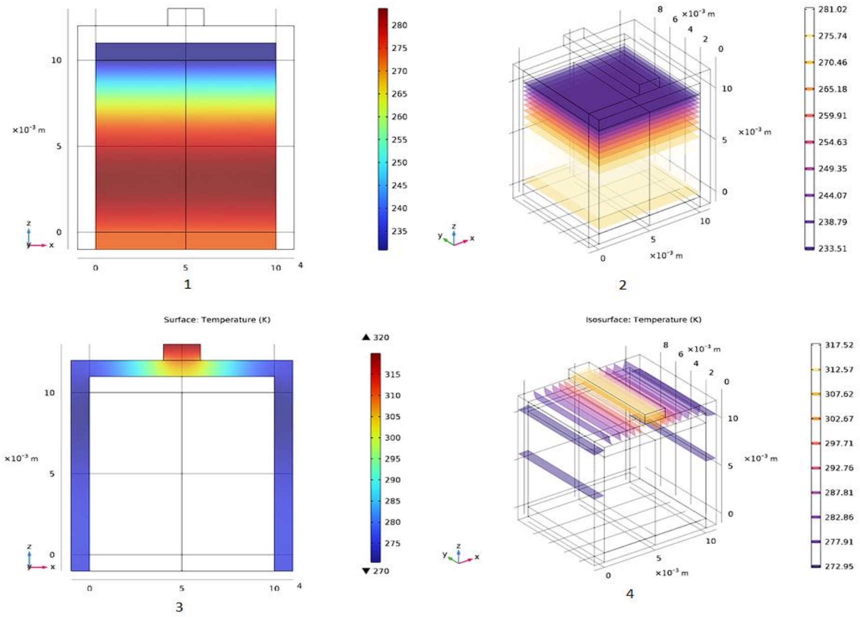

Fig. 6. Computer model of temperature distribution in the module – 1; isothermal surface of thermoelement – 2; distribution of temperature in the heat carrier – 3; isothermal surface of thermoelement – 4.

Table 1.

Parameters of the penetrating thermoelement in the cooling regime

H	**1 (cm)**	**2 (cm)**	**3 (cm)**	**4 (cm)**	**5 (cm)**
U, V	0.0355	0.0355	0.0355	0.0355	0.0355
T_x, K	230.01	230.3	230.62	230.95	231.28
$T_{пов}$, K	265.39	273.84	268.67	269.88	270.64
Q_c, W	0.96038	0.48661	0.32848	0.24934	0.20182
I, A	13.29	6.72	4.5173	3.3956	2.7165
G, m/s	7.7259E-4	8.2136E-4	8.2738E-4	8.3124E-4	8.3277E-4
W, W	0.95107	0.47727	0.31911	0.23997	0.19247
COP	2.03558749	2.039780349	2.04833811	2.068459763	2.092792351

Table 2.

The comparative characteristics of classic and penetrating thermoelement

	Classic thermoelement	**Penetrating thermoelement**
H, cm	1 cm	1 cm
U, V	0.0355	0.0355
T_x, K	241.14	230.01
$T_{пов}$, K	0	265.39
Q_c, W	0.79542	0.96038
I, A	12.14	13.29
G, m/s	0	7.7259E-4
W, W	0.89741	0.95107
COP	1.846	2.036

(fig. 9) are shown with the help of computer modeling.

The results of the modeling are put in the table. The parameters of the penetrating cooling thermoelement for different height of branches, which were calculated with the help of computer modeling, are given in the table 1. Where H – height of thermoelement, U – output voltage, T_x – temperature of cold junction of thermoelement, Q_c – cooling capacity, I – input voltage, G – speed of the coolant, W – consumed power, COP – coefficient of thermoelement productivity is defined as

$$COP = \frac{Q}{UI} \qquad (3)$$

Formula (3) gives the most effective indicators of thermoelectric cooling, when the heat, which is consumed already allocated to the input voltage, reaches the maximum.

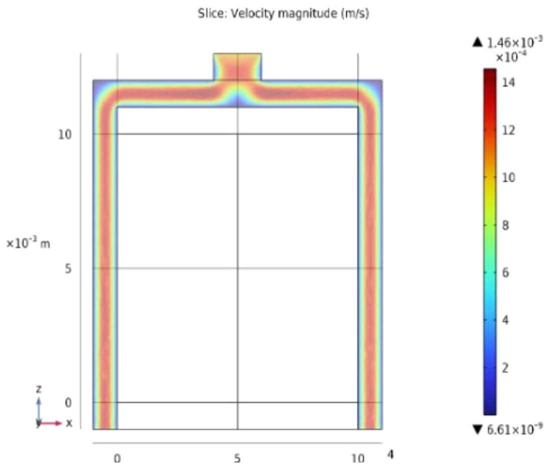

Fig. 7. Distribution of speed in thermoelement.

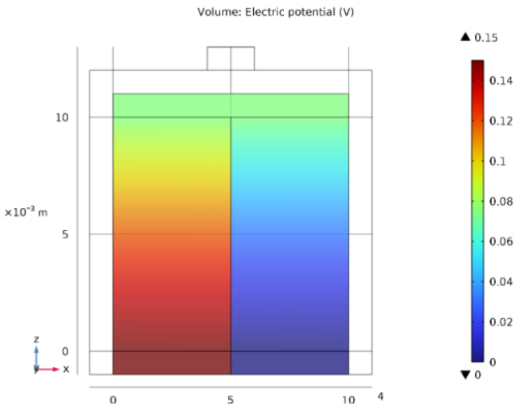

Fig. 8. Allocation of electric potential of thermoelement

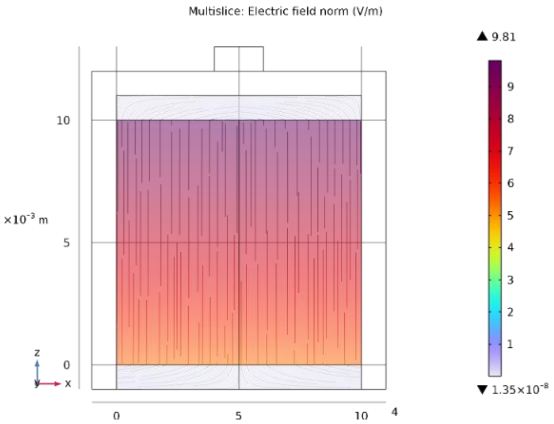

Fig. 9. Allocation of electric field in thermoelement.

When we compare parameters with the classic thermoelement, the theoretical calculations show that the usage of such allocators at the optimal conditions increases the cooling coefficient at 10-30%. The comparative characterization is shown in chart 2.

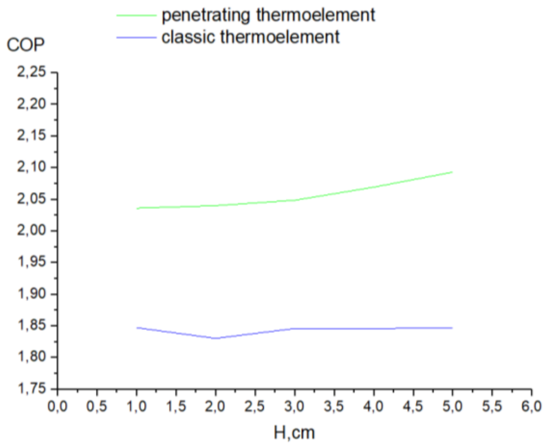

Fig. 10. Graphic of dependence of COP on height of thermoelement.

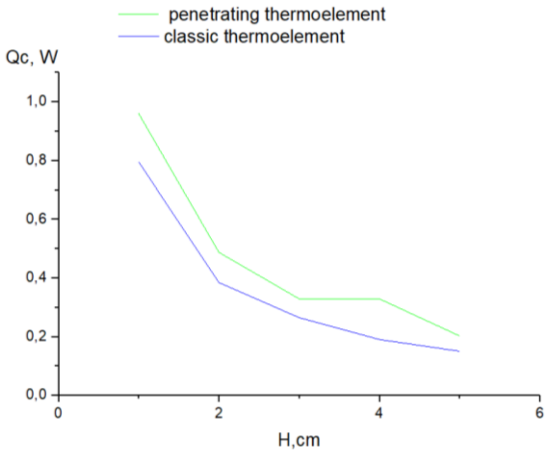

Fig 11. Graphic of dependence of cooling capacity to height of thermoelement.

The obtained results proved the perspectivity of the researches and creation of penetrating thermoelectric modules, and show that in case of geometry and height (1cm) for two modules, the advantage of the penetrating thermoelement is in the better coefficient of productivity of thermoelement at 9.33%. On the base of calculations from table 1, the graphics of dependence of COP (fig. 10) and cooling capacity (fig. 11) on height of thermoelement where built.

Based on the given model of thermoelectric cooler, the mathematic description of the basic processes is given. These processes lead to the mutual transformation of thermal and electric energy in the thermoelectric refrigerators with the help of computer modeling at the COMSOL Multiphysics. With the help of modeling is proved that while changing the conditions of the heat exchange along the height of the branch, we can influence at the volumetric distribution of the sources of heat in the branches of the penetrating thermoelement.

Conclusions

The usage of the penetrating thermoelectric coolers of such transformers of the energy allows to increase the cooling coefficient by 10-30%. The received results demonstrate the perspectivity of the researches and creation of the penetrating cooling thermoelements. They show that, as in case of the height of branch at 1cm, the advantage of the penetrating thermoelement is at the higher cooling productivity of thermoelement at 9.3%.

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Вплив висоти пластин на ефективність проникного термоелемента в режимі охолодження

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У роботі описано фізичну модель проникного термоелемента з розвиненою поверхнею теплообміну для охолодження потоку повітря. Представлено теорію розрахунку та метод комп’ютерного моделювання розподілу температур та потенціалів, визначення ефективності перетворення енергії - холодильного коефіцієнту та холодопродуктивності, досліджено 3D розподіл температур та потенціалів для матеріалу віток термоелемента на основі Bi_2Te_3.

Ключові слова: проникний термоелемент, холодильний коефіцієнт, холодопродуктивність, 3D-модель.