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Simulation of the influence of increasing current density in P- and N-branches of Thermoelectric generators on Thermal processes

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Abstract

This article describes the process of modeling the influence of changes in electric current density in the branches of a thermoelectric generator on the processes of heat conversion in its volume. For this purpose Comsol Multiphysics software was used. Using the program, changes in the distribution of heat and temperature inside thermocouples with varying current density were analyzed. This is an important parameter for optimizing the efficiency of thermoelectric generators. The article also explains the processes of establishing electric currents in thermopile components, the phenomenon of heat transfer in solids, the thermoelectric effect, electromagnetic heat source, the limits of the thermoelectric effect and temperature coupling.

Keywords: Thermoelectric generator, Comsol Multiphysics, thermocouple, temperature dependence.

Introduction

Recently, one of the main directions of energy development is the issue of uninterrupted supply of electricity to all sectors of the national economy. In this regard, one of the main pressing problems of uninterrupted power supply is the use of power generating devices and their improvement. Of course, it is necessary that the device is safe from a technical point of view, does not have a harmful impact on the environment and can provide the opportunity to make maximum use of alternative energy sources. One solution to today's problems is the role of thermoelectric generators, based on the physical process discovered by Seebeck in 1821[1,2].

As mentioned in our previous works[3,4], thermoelectric generators (TEGs) are the main source of electrical energy to ensure proper conversion of thermal energy into electrical energy. Thermoelectric generators can be used in almost any environment where a temperature difference can be created[5]. TEGs also serve as an additional source of electricity that can be used for domestic needs[6]. They are also promising devices for autonomous power supply of facility monitoring systems, medical equipment and other devices. In households using individual boilers for heating, TEGs can also be used for cooling, heating and stabilizing the temperature of food[7].

Despite the wide range of applications, the efficiency of TEG is not yet satisfactory. Although the efficiency of the first thermoelectric generators did not exceed 2%, modern multistage heat generators reach about 13%. This figure is expected to increase to 20% or more due to the development of new semiconductor materials and improvements in their structure[8]. To achieve this goal, most research is aimed at determining the optimal stoichiometric composition of semiconductor materials for thermoelectric converters, improving their production technologies and expanding their areas of application. New materials with a nanoscale structure that have improved thermal conductivity properties are being developed.

But the process of research, preparation and production of thermopile requires significant effort, investment and laboratory equipment. The calculation of the parameters of thermoelectric generators is complicated by many factors, such as the material of the TEG, its electrical parameters, geometric dimensions and the ratio of electrical and thermal characteristics. To solve these problems, simulation is used to optimize the parameters of thermopile elements before production, which helps avoid numerous iterations and is a cost-effective solution[9].

Literature review: In the presented work, it is advisable to choose a modeling method to solve the problem, study existing methods and choose the one that has high accuracy and fast calculations. In particular, the authors of the work[10] proposed a mathematical model of the ring geometry of a thermoelectric generator. And in work[11] a methodology and mathematical model for calculating and optimizing the design of the MFS was developed. The works[12,13] present a method for modeling a microthermoelectric generator based on semiconductor compounds of bismuth and antimony tellurides using the ANSYS Workbench software platform. The paper[14] describes the characteristics of a radioisotope thermoelectric generator (RTG) of a thermal-hydraulic RTG model in the SolidWorks software package. The results of computer simulation of X-ray cooling due to natural circulation are presented. Similar problems were shown and solved in work[15], on the basis of which the problem of optimizing parameters was calculated and simulated depending on the conditions or purposes of using TEG.

But this model does not make it possible to determine what temperatures at the hot and cold ends should be during the TEG design process. According to the analysis, the modeling method in the Comsol Multiphysics program is acceptable for the implementation of the problem, and calculations were carried out using its advantages.

Methodology

In the research, the Comsol Multiphysics[16] software tool was used to model objects and processes. Because with this method, modeling the effect of increasing current density on the heat distribution in thermoelectric generator elements is more accurate. In addition, due to the fact that the program has a library of physical and chemical formulas, the research process becomes easier and more accurate. An important feature of Comsol Multiphysics software is the ability to simulate complex heat transfer processes. To calculate heat transfer on the surface of bodies of various geometric shapes, a set of figures is used.

Although we do not need this for research, modeling in this way makes it possible to calculate radiative transfer under conditions of free and forced convection, calculate heat transfer 8 in laminar and turbulent regimes, in vacuum and in continuous media. But to model phenomena and objects, it is important to understand the nature of thermoelectric phenomena, such as the Seebeck effect, Pelte effect and Thomson effect, which arise due to the interdependence of heat transfer and charge transfer processes. Once you know the concepts, you can focus directly on the modeling processes of thermoelectric generators.

Results and Discussion

Having sufficient information about the capabilities of the Comsol Multiphysical program, to simulate the effect of increasing current density on the heat distribution in the elements of thermoelectric generators, first run the program and enter its geometric dimensions. When entering geometric dimensions, these parameters can be entered as constants or variables (Figure-1). This makes it possible to correct and optimize the processes occurring there, changing its geometric dimensions to increase the efficiency of the thermogenerator.

Figure-2 shows how input parameters are indicated by symbols and described by the program. For the sample, the shape of the thermogenerator was taken in the form of a parallelepiped, its geometric dimensions were determined by the variables A (base width), B (base length), H (element height), and their values were initially 4 mm, 4 mm and 6 mm, respectively. The current density is designated by the symbol J_0, the base temperature T_0 (cold end) is assumed to be 20^0C.

Then, using the capabilities of the program, the constituent materials of the thermogenerator and the materials of the contact plates are selected[6]. Here it is worth mentioning another important feature of the program, which is that the program includes all the chemical and physical parameters of the chemical substances (Bi, Te, Sb...) used to create elements of a thermoelectric generator. This allows you to obtain the results of theoretical studies with high accuracy, and also save time spent on entering redundant data into the modeling process.

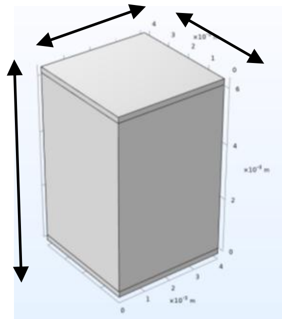


Figure-1: Entering the geometric dimensions of a thermogenerator element using the Comsol Multiphysical software tool.

Parameters: Iron layers with a contact coating thickness of 0.2 mm. Current density 10-200 A/cm^2. Base temperature 20°C. The Seebeck coefficient of iron is 6.5 mV/K. The thermoelement material is bismuth telluride.

The parameters Current conservation, Electrical insulation, Initial values, Earth, Normal current density of the electric current parameters in the elements of the thermogenerator are configured from the Electric currents section of the program and the initial values of the electric current are entered. Figure-2 shows the process of adjusting the electric current parameters. In thermocouples, the flow of electric current causes a temperature difference due to the Pelte effect, and the program $\nabla \cdot J = Q_{j,V}$ performs processes based on the laws of formulas such as, $J = \sigma E + J_e$ and $E = -\nabla V$.

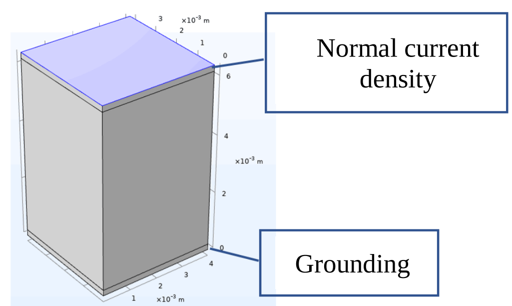


Figure-2: Parameterization of the electric current of the thermogenerator element using Comsol Multiphysics software.

The next process in building our model is setting the parameters of the “Heat Transfer in Solids” program. Understanding that the temperature gradient in thermocouples leads to the appearance of thermo-EUC due to the Seebeck effect, the program implements the process through the laws of the following formulas.

$$\rho C_{\rho} u \cdot \nabla T + \nabla \cdot q = Q + Q_{ted} \quad (1)$$

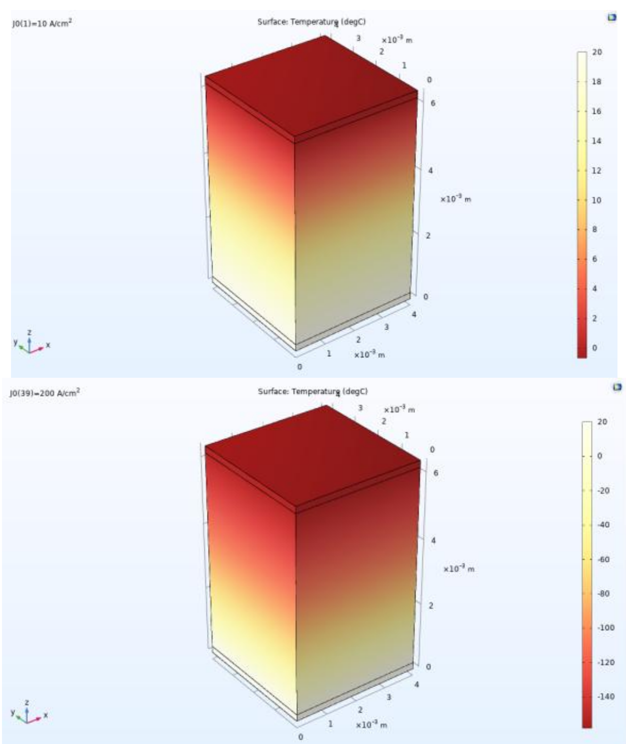
$$q = -k\nabla T \quad (1)$$

In the next process of building a model from the "Multiphysics" section of the program, the "Thermoelectric effect" and "Electromagnetic heating" settings are made. The processes of thermoelectric influence $\rho = ST$ are carried out according to formulas $C_{\rho}\frac{dT}{dt} + \nabla(-k\nabla T + PJ) = Q$, $q = PJ$ and electro-magnetic heating through formul as $J_e = -\sigma S\nabla T$ and $Q_E = J \cdot E$.

Above we examined phenomena that allow us to see all cases associated with physical processes occurring along the dimensions of the thermocouple. It's time to implement a process that allows you to observe and draw conclusions from these events. To do this, go to the Training section of the program. In our research, we did this work by looking at two different situations. In the first case, electromagnetic heating, that is, resistive losses, is not taken into account, and in the second case, resistive losses are taken into account. In this section, we have also added the Optimize feature to our resume. In the optimization process of our study, the SNOPT method was used.

Discussion: The ability to analyze the changes occurring inside the thermocouple by changing the current density, which is considered an important parameter for the TB obtained from the simulation, and the heat distribution, is shown in Figure-3a, 3b, 4a, 4b.

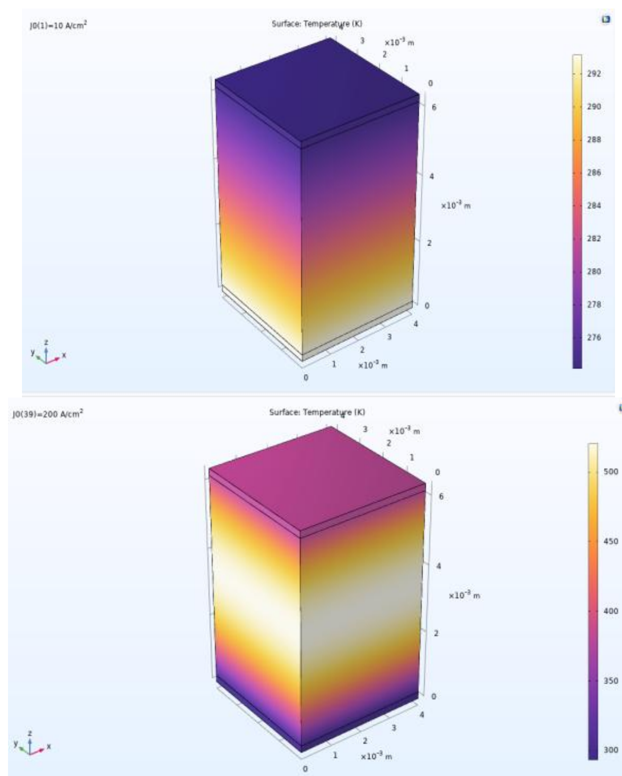
If pay attention to Figure-3a and 3b, without taking into account resistive losses, you can determine that the temperature difference does not increase with increasing current density in thermoelements. But, of course, in real processes it is necessary to take into account resistive losses. If you pay attention to Figure-4a and 4b, you will notice that the temperature difference increases up to a certain current density value and then decreases. To make this situation more clear, it can be clearly seen in the graph presented in Figure-5, obtained using the program.



a

b

Figure-3: Effect of changing current density on temperature (resistive losses are not taken into account) a) Current density 10 A/cm^2; b) Current density 200 A/cm^2.



a

b

Figure-4: Effect of changing current density on temperature (resistive losses are taken into account): a) Current density 10 A/cm ^{2}; b) Current density 200 A/cm^2.

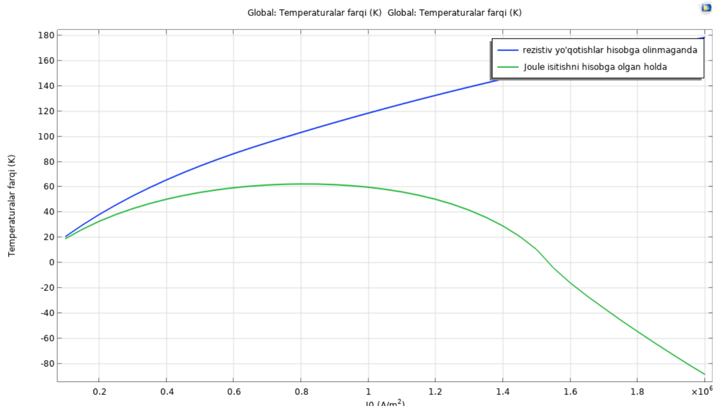


Figure-5: Effect of increasing current density in thermocouples on temperature.

The blue line in the Figure-5 depicts the case when resistive losses are not taken into account. If you pay attention to the direction of the line, you can see that the temperature difference increases almost linearly with increasing current density. If the resistive losses represented by the green line are taken into account, the confirmation of the above points can be clearly seen.

Conclusion

In conclusion, it can be noted that modeling processes today play an important role in the development of science. Today there are many software tools for modeling in different directions. In our study, we used the Comsol Multiphysics software tool to analyze various thermocouple parameters and were able to analyze the desired results: i. it was noticed that a change in current density affects the temperature difference of thermocouples; ii. the greatest temperature difference was achieved at a current density of 81.218 A/cm^2 in a thermocouple with geometric dimensions of 4 mm, 4 mm and 6 mm.

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