DOI: 10.63527/1607-8829-2024-3-74-85

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UNIVERSAL THERMOELECTRIC GENERATOR WITH HEAT REMOVAL BY WATER TANKS

The work describes the design of a universal thermoelectric generator that can operate from any heat source - heated flat surfaces of stoves, gas or multi-fuel tourist primus, open flame, etc. The electrical energy received from the generator with a power 20-40 W provides autonomous power supply for various low-power radio electronic equipment, portable radio stations, mobile communication systems, lighting, as well as charging universal mobile batteries - power banks. To remove heat from the cold side of thermoelectric modules, tanks with water are used, which can be used for domestic purposes. The results of bench and field experimental studies of the developed generator are presented. Bibl. 30, Figs. 10, Table. 1.

Key words: thermoelectric generator, thermoelectric modules, test, electric power.

Introduction

At present, the use of chemical current sources remains traditional as autonomous sources of electricity supplying low-power radio-electronic equipment. However, their significant disadvantages are self-discharge and low reliability, especially at low ambient temperatures and under conditions of increased mechanical loads.

In this regard, autonomous thermoelectric power sources operating from the heat of combustion of various fuels are especially promising. They can have a long service life, have increased reliability and resistance to climatic and impact loads, are universal, silent in operation and easy to use. Scientists and engineers from many countries are actively working on the creation of such sources. Thermoelectric generators with an electric power of 2–100 W, which are intended for charging mobile phones, power banks, radio stations, and navigators during travel and hiking, lighting and other needs, have been developed by a number of companies (TES, Biolite, etc.) [1–13].

The main obstacle to the widespread practical use of thermoelectric energy converters is their relatively high cost, primarily due to the high price of the thermoelectric material they are made of [14-16].

A series of studies conducted at the Institute of Thermoelectricity (Ukraine) [17-30] was aimed at solving this problem. It allowed achieving a significant reduction in the cost of generators by optimizing the technology for obtaining thermoelectric materials, reducing their consumption by miniaturizing thermoelectric generator modules, developing optimal designs for such generators,

specialized in the conditions of their use, and equipment for quality control of thermoelectric materials and modules.

The purpose of this work is to conduct, at the Institute of Thermoelectricity, a series of bench and field experimental studies of universal thermoelectric generators of various modifications.

1. Description of the design of a universal thermoelectric generator

A diagram of the universal thermoelectric generator developed at the Institute of Thermoelectricity (Ukraine) is shown in Fig. 1.

The generator consists of thermoelectric generator modules 1 of the "Altec-1061" type, placed between the hot 2 and cold 4 heat exchangers, which are interconnected by screws 3. To connect to a water tank, the generator has special springs with hooks 5, which provide the necessary pressing force of the cold heat exchanger to the bottom of the tank. In order to stabilize the output voltage, an electronic unit 9 is used, connected to the generator by a cable 6 with fire-resistant insulation. And to control the temperatures of the heat exchangers on their inner surface in the generator, two resistance thermometers 7 and 8 are placed.

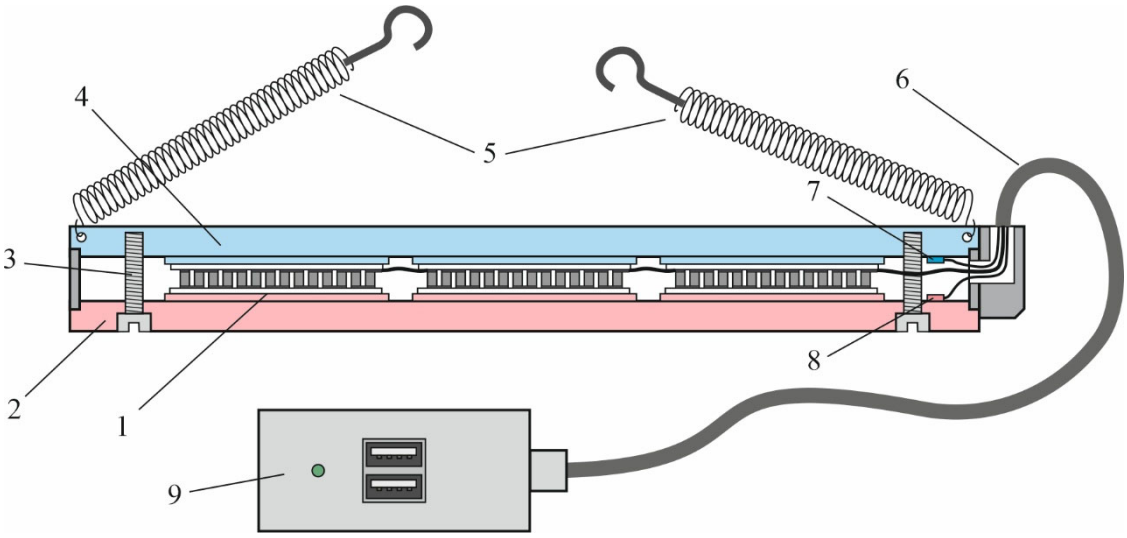

Fig.1. A diagram of the universal thermoelectric generator:
1 – thermoelectric generator modules; 2 – hot heat exchanger; 3 – connecting screws;
4 – cold heat exchanger; 5 – springs with hooks for attaching to water tank;
6 –cable with fire-resistant insulation; 7, 8 –resistance thermometers;
9 – electronic output voltage stabilization unit

The appearance of a universal thermoelectric generator, which can be mounted on a 2-5 liter water tank, is shown in Fig. 2. The generator can operate from any heat source - heated flat surfaces of stoves, gas or multi-fuel tourist primus, open flame, etc. The tank (pan) is used to heat water or cook food. The heat released during fuel combustion passes through the thermoelectric modules and is dissipated in the volume of the pot, heating the water in it. In this case, temperature differences are created between the heat exchangers and, accordingly, between the hot and cold sides of the thermoelectric modules. This leads to the appearance of an electric voltage on the thermoelectric modules, the magnitude of which is proportional to this temperature difference. The power that can be obtained from the thermoelectric modules directly depends on the power of the heat source.

Fig.2. Appearance of universal thermoelectric generator:
1 – thermoelectric generator; 2 – electronic unit of output voltage stabilization;
3 – hooks on springs for attaching the generator to a water tank

Consumers usually require a stable standard voltage, which is the most commonly used - 5V DC. This voltage is used in most chargers, as well as for charging power banks.

To stabilize the output voltage, an electronic unit is used, which is made on the basis of a step-up step-down voltage converter. Such converters usually have threshold values of the input voltage, within which they operate. At the beginning of the operation of the thermoelectric generator, the temperature difference between the hot and cold heat exchangers of the generator will be small and only when it increases during the heating process, the voltage produced by the thermoelectric modules will be sufficient to start the operation of the output voltage stabilization circuit. The time during which the generator reaches the output mode will directly depend on the power of the heat source. The output voltage from the electronic unit is output to two paired USB connectors. The indicator of the appearance of the output voltage on the connector is the illumination of a green LED, which is located next to the USB connector. The generator is also equipped with an additional power cable with a voltage converter from 5V to 12V. Such voltage may also be required to power other devices. This cable can be used both with the generator's electronic unit and with a power bank.

Thermoelectric modules have a specific operating temperature range and require protection against overheating. Therefore, temperature sensors are installed in the heat exchange surfaces, which are included in the light-sound alarm circuit located in the electronic unit.

To prevent damage to the generator, it is necessary to monitor the temperature regimes of its operation. When using various heat sources, especially open fire, overheating of the heat exchange elements of the thermoelectric block of the generator is possible. An alarm circuit warns of overheating of the heat exchange plates of the thermoelectric block. It is triggered when the temperature of the cold heat exchanger becomes more than 100°C (the boiling point of water), as well as when the temperature of the hot heat exchanger becomes more than 300°C. When these temperatures are exceeded, the light and sound alarm is triggered - the buzzer sounds and one of the LEDs lights up. If the blue one lights up, it means that the water has boiled away, so you need to add water. Red light and buzzer sound indicate that the temperature of the hot heat exchanger is too high. In this case, you should move the thermoelectric block of the generator, which is located on the heat source, to a less hot place or reduce the intensity of fuel combustion. The LED indicators are located in the holes in the body of the electronic

unit on the side of the power cable. There are also holes for the buzzer sound output.

The developed thermoelectric generator uses highly efficient generator modules of the Altec-1061 type with an extended operating temperature range. The modules are made of a material based on bismuth telluride and have special contact structures that allow them to withstand temperatures on the hot side up to 350°C. The electrical power of the modules is 8-10 W, the efficiency is up to 6.5%.

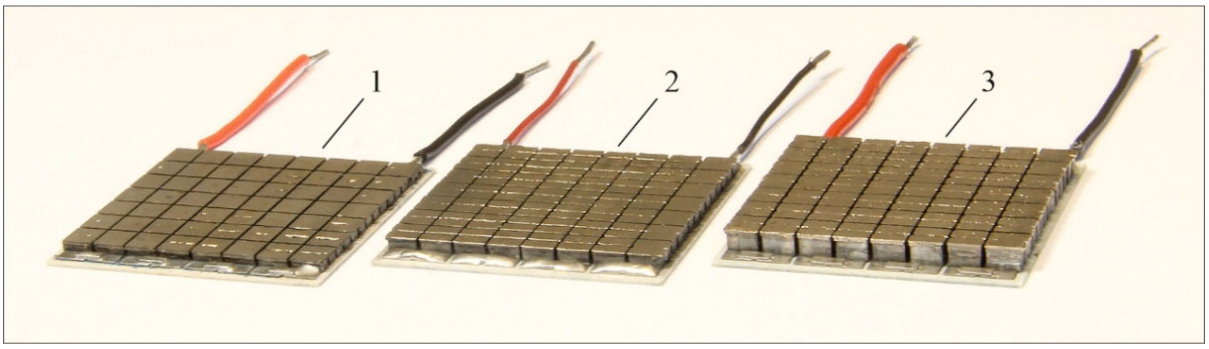

Fig.3. Generator thermoelectric modules of the "Altec-1061" type with different heights of thermoelement legs h: 1) h = 1.6 mm; 2) h = 2.1 mm; 3) h = 3.2 mm

For experimental research, thermoelectric generators of four modifications were manufactured, which differ in geometric dimensions, the number of thermoelectric modules and the height of the legs of these modules. The modules are manufactured using the same technology, but with different leg heights (Fig. 3). Reducing the height, as shown by theoretical and experimental studies, even by 1.5–2 times leads to a slight decrease in the efficiency of the modules, but allows you to significantly reduce the material consumption for their manufacture, and, consequently, reduce the cost of the thermoelectric generator.

The main design features of various modifications of the developed thermoelectric generator are given in Table 1. All modifications have the same thickness of the hot and cold heat exchangers - 5 mm. In modifications A, B and C, heat exchangers with a diameter of 160 mm are used. These generators contain three thermoelectric modules of the “Altec-1061” type with leg heights of 1.6 mm, 2.1 mm and 3.2 mm, respectively. Modification D has increased overall dimensions (diameter of heat exchangers - 180 mm) and contains four thermoelectric modules of the "Altec-1061" type with a leg height of 3 mm. This is a modification for obtaining greater electrical power and it is advisable to use it with water tanks of larger volume - 3–7 liters.

Table 1.

Design features of various modifications of the thermoelectric generator

Modification	Diameter of heat exchangers, mm	Number of modules	Height of module legsв, mm	Recommended capacity of the container, l
A	160	3	3.2	2-5
B	160	3	2.1	2-5
C	160	3	1.6	2-5
D	180	4	3.2	3-7

2. Results of experimental studies of the developed generator

The tests of the developed thermoelectric generators were carried out both in laboratory and field conditions. In the first case (Fig. 4), a gas burner 1 was used as a heat source. To measure the parameters of the generator 2, fixed on the tank 3, a control unit for measuring the parameters of thermoelectric energy converters of the Altec-10002 installation 6, developed at the Institute of Thermoelectricity, an electronic load 5 and a temperature recorder 7 were used.

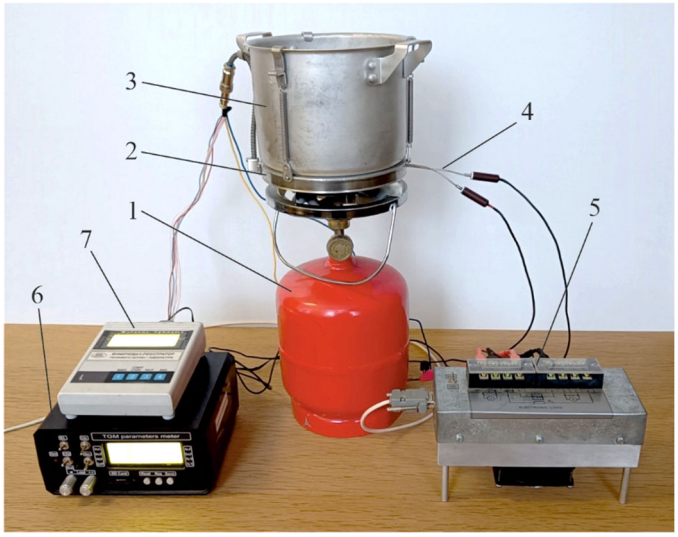

Fig. 4. Bench tests of a thermoelectric generator:
1 –heat source (gas burner); 2 – thermoelectric generator; 3 – 2.5 l water tank; 4 –thermocouples;
5 – electronic load; 6 – control unit for measuring parameters of thermoelectric energy converters of the "Altec-10002" installation; 7 – temperature recording unit

The results of laboratory tests in the form of time dependences of the electric power of thermoelectric generators of modifications A, B, C and D are shown in Fig. 5 – Fig. 8. As can be seen from these figures, after the burner is ignited, the electric power of the generator quickly increases to its maximum value and then gradually decreases to the operating mode as the water in the tank heats up, and, accordingly, the temperature of the cold heat exchanger rises.

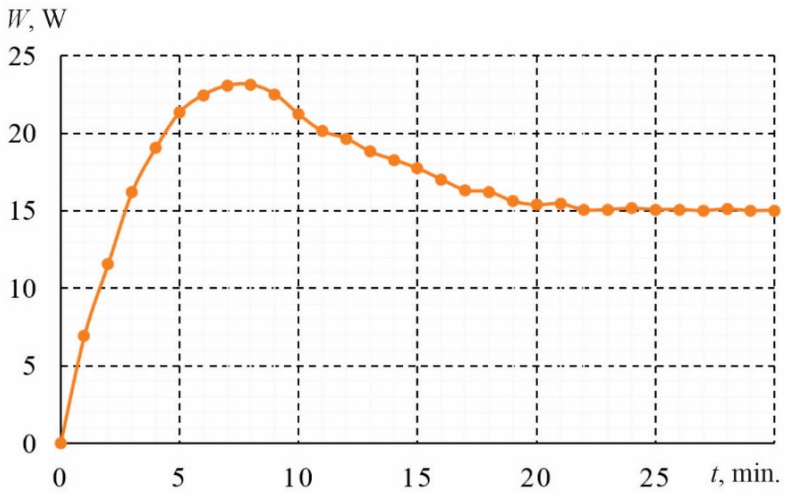

Fig. 5. Time dependence of the electric power of a thermoelectric generator of modification A with a capacity of 2.5 l (laboratory studies on a gas burner)

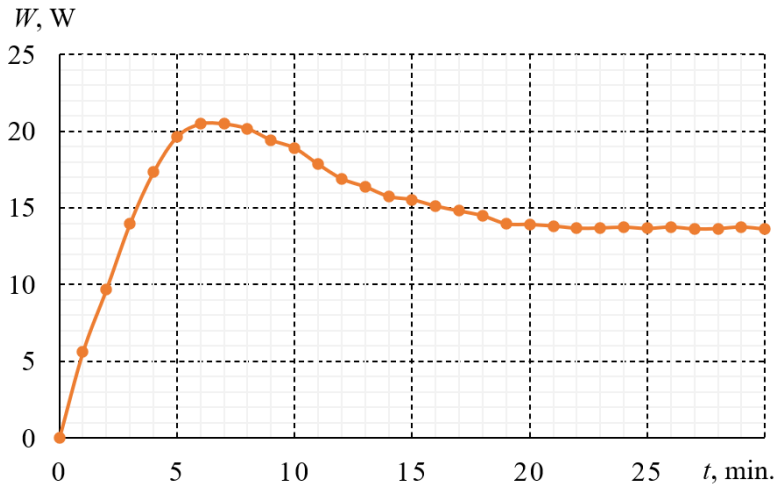

Fig. 6. Time dependence of the electric power of a thermoelectric generator of modification B with a capacity of 2.5 l (laboratory studies on a gas burner)

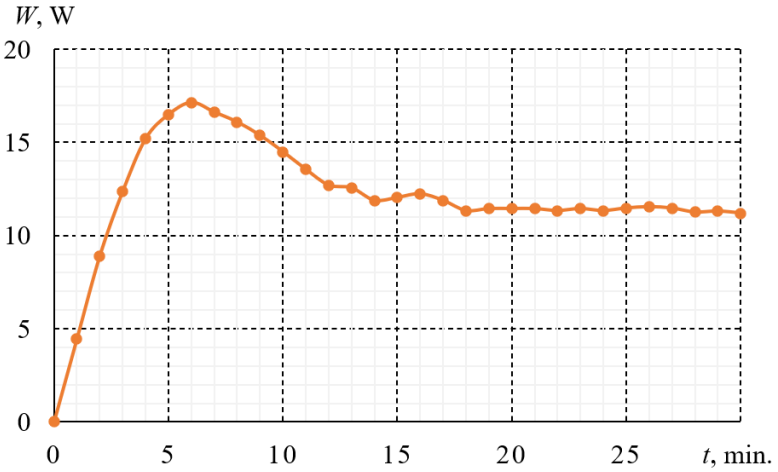

Fig. 7. Time dependence of the electric power of a thermoelectric generator of modification C with a capacity of 2.5 l (laboratory studies on a gas burner)

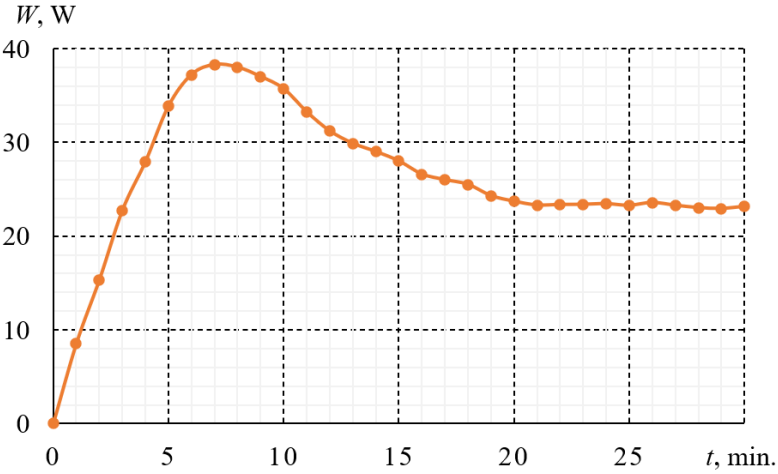

Fig. 8. Time dependence of the electric power of a thermoelectric generator of modification D with a capacity of 3.5 l (laboratory studies on a gas burner)

Thus, the maximum electric power of the generators of modifications A, B and C was 23, 21 and 17 W, respectively. The generator of modification D, containing 4 modules, has an increased power - more than 35 W. The working values of the electric power of the generators when water boils in the tank are approximately 30-35% lower than the maximum.

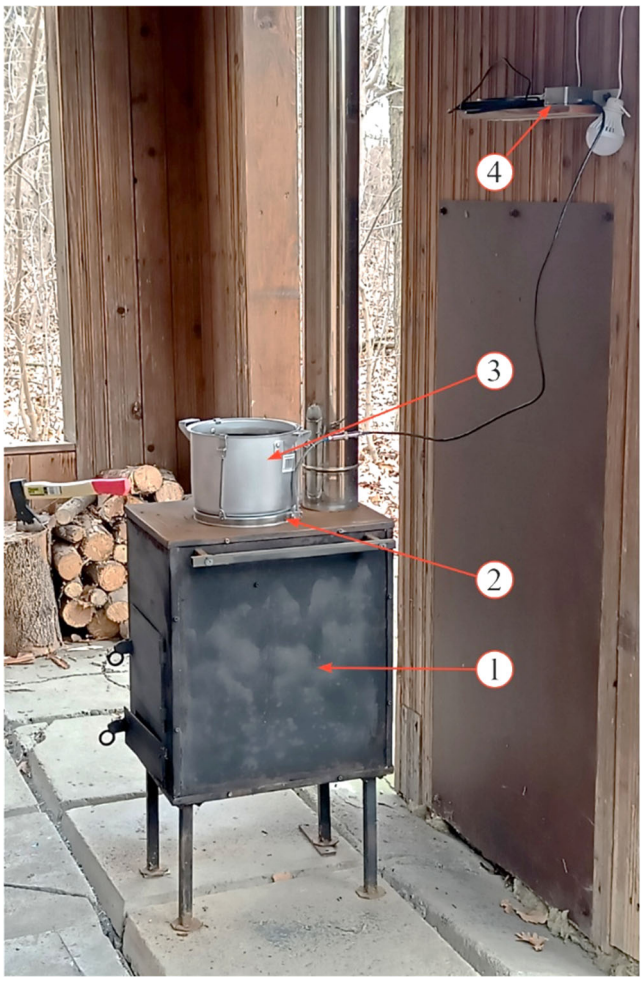

Fig. 9. Field tests of a thermoelectric generator of modification D with a capacity of 3.5 l on a wood-burning stove: 1 – wood-burning stove; 2 – thermoelectric generator; 3 – water tank; 4 – electronic output voltage stabilization unit

This power of generators of all four modifications is enough to power various low-power radio electronic equipment, portable radio stations, mobile communication systems, lighting, as well as charging universal mobile batteries - power banks.

Since, as is known, the main part of the cost of a thermoelectric energy converter is the cost of the thermoelectric material it is made of, the results obtained indicate the possibility of significantly reducing the cost of thermoelectric generators with heat removal by water tanks using thermoelectric modules with reduced height of legs.

Field studies were conducted on a wood-burning stove (Fig. 9), which was also developed and manufactured at the Institute of Thermoelectricity. Fig. 10 shows the time dependence of the power of the generator of modification D for 1 hour from the moment of ignition of the stove. As can be seen from Figs. 9 and 10, due to the high efficiency of the stove, the electric power of the generator in field conditions differs slightly from that obtained on a laboratory bench.

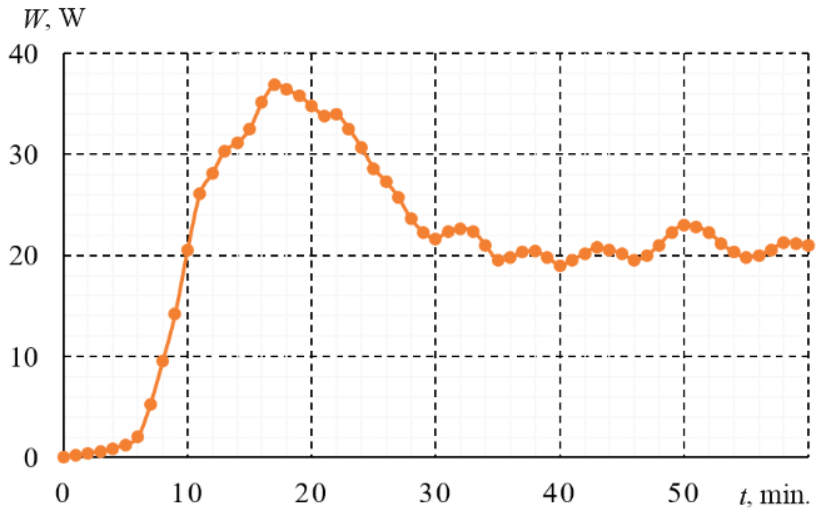

Fig. 10. Time dependence of the electric power of a thermoelectric generator of modification D with a capacity of 3.5 l (field research on a wood-burning stove)

Thus, the developed universal thermoelectric generator, combined with a wood-burning stove, forms an autonomous thermoelectric source of electricity and heat, providing the production of 20-40 W of electrical power, 1-2 kW of thermal energy, as well as heating 3-7 liters of water for cooking and other household needs.

Conclusions

1. The design of a universal thermoelectric generator is described, which can operate from any heat sources - heated flat surfaces of stoves, gas or multi-fuel tourist primus, open flame, etc. To remove heat from the cold side of thermoelectric modules, containers with water are used, which can be used for household needs.
2. The results of laboratory experimental studies of the developed generator of four modifications, differing in geometric dimensions, the number of thermoelectric modules and the height of the legs of these modules, are presented. The maximum electric power of the generators of modifications A, B and C was 23, 21 and 17 W, respectively. The generator of modification D, containing 4 modules, has an increased power - more than 35 W. Working values of the electric power of the generators at the moment of boiling water in the tank are approximately 30-35% lower than the maximum.
3. Field studies of the developed generator on a wood-burning stove were conducted. It was established that a universal thermoelectric generator in combination with a wood-burning stove forms an autonomous thermoelectric source of electricity and heat, which provides the production of 20-40 W of electrical power, 1-2 kW of thermal energy, as well as heating 3-7 liters of water for cooking and other household needs.

References

1. TEG-BS-5W-5V-1. Available at: https://www.thermonamic.com/pro_view.asp?id=887
2. TEG-BS-10W-5V-2. Available at: https://www.thermonamic.com/pro_view.asp?id=876
3. Biolite CampStove. Available at: https://www.bioliteenergy.com/products/campstove-complete-cook-kit
4. CN216524233U. Thermoelectric water kettle water level detection circuit. Published 13.05.2022.

5. CN105167597B. A kind of thermo-electric generation hot-water bottle. Published 02.01.2018.
6. CN209391675U. A kind of heating vessel. Published 17.09.2019.
7. CN208806757U. Thermo-electric generation wild cooker. Published 30.04.2019.
8. GB2605345A. Cooking vessel. Published 28.09.2022.
9. Montecucco, A., Siviter, J., & Knox, A. R. (2017). Combined heat and power system for stoves with thermoelectric generators. Applied Energy, 185(P2), 1336-1342. https://doi.org/10.1016/j.apenergy.2015.10.132
10. Żołądek, M., Papis, K., Kuś, J., Zając, M., Figaj, R., & Rudykh, K. (2020). The Use of Thermoelectric Generators With Home Stoves. E3S Web Conf., 173, 03005. https://doi.org/10.1051/e3sconf/202017303005
11. Wood stove Thermoelectric Generator Rabbit Ears. Available at: https://thermoelectric-generator.com/product/wood-stove-thermoelectric-generator-rabbit-ears/
12. 45-watt teg generator for wood stoves with air-cooling. Available at: https://www.tegmart.com/thermoelectric-generators/wood-stove-air-cooled-45w-teg
13. Thermoelectric Power Generator for fireplace heater. Available at: http://www.thermonamic.com/pro_view.asp?id=828
14. Rowe, D. M. (2012). Modules, Systems, and Applications in Thermoelectrics (1st ed.). CRC Press. https://doi.org/10.1201/b11892
15. Vikhor, L., & Kotsur, M. (2023). Evaluation of Efficiency for Miniscale Thermoelectric Converter under the Influence of Electrical and Thermal Resistance of Contacts. Energies, 16, 4082-1 - 22. https://doi.org/10.3390/en16104082
16. Anatychuk, L. I., Lysko, V. V., & Prybyla, A. V. (2022). Rational areas of using thermoelectric heat recuperators. Journal of Thermoelectricity, 3-4, 43–67.
17. Rybchakov, D. E. (2023). Use of Computer Simulation for Optimization of Technological Modes of Manufacturing Thermoelectric Materials Based on *Bi-Te* Obtained by Vertical Zone Melting Method. Journal of Thermoelectricity, 2, 81-86.
18. Anatychuk, L. I., & Korop, M. M. (2023). Application of Machine Learning to Predict the Properties of Bi_2Te_3-Based Thermoelectric Materials. Journal of Thermoelectricity, 2, 59-71.
19. Gorsky, P. V. (2023). Probability Theory of Degradation of Thermoelectric Energy Converters and Its Use to Determine the Reliability of Thermoelectric Materials. Journal of Thermoelectricity, 2, 50-58.
20. Lysko, V. V., & Tudoroi, P. F. (2019). Computer simulation of extrusion process of Bi_2Te_3-based tape thermoelectric materials. Journal of Thermoelectricity, 2, 58–65.
21. Mykhailovsky, V. Y., Lysko, V. V., Antoniuk, V. V., & Maksymuk, M. V. (2017). Research on thermoelements based on *n-PbTe* and *p*-TAGS materials for thermoelectric generator cascade module. Journal of Thermoelectricity, 3, 36–44.
22. Lysko, V. V., & Nitsovich, O. V. (2023). Computer Optimization of the Vertical Zone Melting Method for Manufacturing Flat Ingots of Thermoelectric Materials Based on Bi_2Te_3. Journal of Thermoelectricity, 4, 36-45.
23. Konstantynovych, I. A., Ivanochko, M. M., & Kadelnyk, K. O. (2024). Design of a portable universal thermoelectric generator. Journal of Thermoelectricity, 1-2, 78–89.
24. L.I. Anatychuk, A.V. Prybyla, M.M. Korop, Yu.I. Kiziuk, I.A. Konstantynovych. (2024) Thermoelectric power sources using low-grade heat (Part 1). *Journal of Thermoelectricity*, (1-2), 90–96.
25. Anatychuk, L. I., & Lysko, V. V. (2012). Investigation of the effect of radiation on the precision of thermal conductivity measurement by the absolute method. *Journal of Thermoelectricity*, 1, 65–73.

26. Anatychuk, L. I., & Lysko, V. V. (2012). Modified Harman's method. *AIP Conference Proceedings*, 1449, 373–376. https://doi.org/10.1063/1.4731574
27. Anatychuk, L. I., Havrylyuk, N. V., & Lysko, V. V. (2012). Methods and equipment for quality control of thermoelectric materials. *Journal of Electronic Materials*, 41(6), 1680–1685. https://doi.org/10.1007/s11664-012-1973-1
28. Anatychuk, L. I., & Lysko, V. V. (2021). Determination of the temperature dependences of thermoelectric parameters of materials used in generator thermoelectric modules with a rise in temperature difference. *Journal of Thermoelectricity*, 2, 71–78.
29. Anatychuk, L. I., Lysko, V. V., & Havryliuk, M. V. (2018). Ways for quality improvement in the measurement of thermoelectric material properties by the absolute method. *Journal of Thermoelectricity*, 2, 90–100.
30. Anatychuk, L. I., Lysko, V. V., Havryliuk, M. V., & Tiumentsev, V. A. (2018). Automation and computerization of measurements of thermoelectric parameters of materials. *Journal of Thermoelectricity*, 3, 80–88.

Submitted:10. 05.2024.

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УНІВЕРСАЛЬНИЙ ТЕРМОЕЛЕКТРИЧНИЙ ГЕНЕРАТОР З ВІДВЕДЕННЯМ ТЕПЛА ЄМНОСТЯМИ З ВОДОЮ

У роботі наведено опис конструкції універсального термоелектричного генератора, що може працювати від довільних джерел тепла – нагрітих плоских поверхонь пічок, газових або мультипаливних туристичних примусів, відкритого полум'я тощо. Отримана від генератора електрична енергія потужністю 20-40 Вт забезпечує автономне живлення різної малопотужної радіоелектронної апаратури, портативних радіостанцій, систем мобільного зв'язку, освітлення, а також заряджання універсальних мобільних батарей – повербанків. Для відведення тепла від холодної сторони термоелектричних модулів використовуються ємності з водою, яка може використовуватись для побутових потреб. Наведено результати стендових та польових експериментальних досліджень розробленого генератора. Бібл. 30, рис. 10, табл. 1.

Ключові слова: термоелектричний генератор, термоелектричні модулі, випробування, електрична потужність.

Література

1. TEG-BS-5W-5V-1. Available at: https://www.thermonamic.com/pro_view.asp?id=887
2. TEG-BS-10W-5V-2. Available at: https://www.thermonamic.com/pro_view.asp?id=876
3. Biolite CampStove. Available at: https://www.bioliteenergy.com/products/campstove-complete-cook-kit
4. CN216524233U. Thermoelectric water kettle water level detection circuit. Published 13.05.2022.
5. CN105167597B. A kind of thermo-electric generation hot-water bottle. Published 02.01.2018.
6. CN209391675U. A kind of heating vessel. Published 17.09.2019.
7. CN208806757U. Thermo-electric generation wild cooker. Published 30.04.2019.
8. GB2605345A. Cooking vessel. Published 28.09.2022.
9. Montecucco, A., Siviter, J., & Knox, A. R. (2017). Combined heat and power system for stoves with thermoelectric generators. Applied Energy, 185(P2), 1336-1342. https://doi.org/10.1016/j.apenergy.2015.10.132
10. Żołądek, M., Papis, K., Kuś, J., Zając, M., Figaj, R., & Rudykh, K. (2020). The Use of Thermoelectric Generators With Home Stoves. E3S Web Conf., 173, 03005. https://doi.org/10.1051/e3sconf/202017303005
11. Wood stove Thermoelectric Generator Rabbit Ears. Available at: https://thermoelectric-generator.com/product/wood-stove-thermoelectric-generator-rabbit-ears/
12. 45-watt teg generator for wood stoves with air-cooling. Available at: https://www.tegmart.com/thermoelectric-generators/wood-stove-air-cooled-45w-teg
13. Thermoelectric Power Generator for fireplace heater. Available at: http://www.thermonamic.com/pro_view.asp?id=828
14. Rowe, D. M. (2012). Modules, Systems, and Applications in Thermoelectrics (1st ed.). CRC Press. https://doi.org/10.1201/b11892
15. Vikhor, L., & Kotsur, M. (2023). Evaluation of Efficiency for Miniscale Thermoelectric Converter under the Influence of Electrical and Thermal Resistance of Contacts. Energies, 16, 4082-1 - 22. https://doi.org/10.3390/en16104082
16. Anatychuk, L. I., Lysko, V. V., & Prybyla, A. V. (2022). Rational areas of using thermoelectric heat recuperators. *Journal of Thermoelectricity*, 3-4, 43–67.
17. Rybchakov, D. E. (2023). Use of Computer Simulation for Optimization of Technological Modes of Manufacturing Thermoelectric Materials Based on *Bi-Te* Obtained by Vertical Zone Melting Method. *Journal of Thermoelectricity*, 2, 81-86.
18. Anatychuk, L. I., & Korop, M. M. (2023). Application of Machine Learning to Predict the Properties of Bi_2Te_3-Based Thermoelectric Materials. *Journal of Thermoelectricity*, 2, 59-71.
19. Gorsky, P. V. (2023). Probability Theory of Degradation of Thermoelectric Energy Converters and Its Use to Determine the Reliability of Thermoelectric Materials. *Journal of Thermoelectricity*, 2, 50-58.
20. Lysko, V. V., & Tudoroi, P. F. (2019). Computer simulation of extrusion process of Bi_2Te_3-based tape thermoelectric materials. *Journal of Thermoelectricity*, 2, 58–65.
21. Mykhailovsky, V. Y., Lysko, V. V., Antoniuk, V. V., & Maksymuk, M. V. (2017). Research on thermoelements based on *n-PbTe* and *p*-TAGS materials for thermoelectric generator cascade module. *Journal of Thermoelectricity*, 3, 36–44.
22. Lysko, V. V., & Nitsovich, O. V. (2023). Computer Optimization of the Vertical Zone Melting Method for Manufacturing Flat Ingots of Thermoelectric Materials Based on Bi_2Te_3. *Journal of Thermoelectricity*, 4, 36-45.

23. Konstantynovych, I. A., Ivanochko, M. M., & Kadelnyk, K. O. (2024). Design of a portable universal thermoelectric generator. *Journal of Thermoelectricity*, 1-2, 78–89.
24. L.I. Anatychuk, A.V. Prybyla, M.M. Korop, Yu.I. Kiziuk, I.A. Konstantynovych. (2024) Thermoelectric power sources using low-grade heat (Part 1). *Journal of Thermoelectricity*, (1-2), 90–96.
25. Anatychuk, L. I., & Lysko, V. V. (2012). Investigation of the effect of radiation on the precision of thermal conductivity measurement by the absolute method. Journal of Thermoelectricity, 1, 65–73.
26. Anatychuk, L. I., & Lysko, V. V. (2012). Modified Harman's method. *AIP Conference Proceedings*, 1449, 373–376. https://doi.org/10.1063/1.4731574
27. Anatychuk, L. I., Havrylyuk, N. V., & Lysko, V. V. (2012). Methods and equipment for quality control of thermoelectric materials. *Journal of Electronic Materials*, 41(6), 1680–1685. https://doi.org/10.1007/s11664-012-1973-1
28. Anatychuk, L. I., & Lysko, V. V. (2021). Determination of the temperature dependences of thermoelectric parameters of materials used in generator thermoelectric modules with a rise in temperature difference. *Journal of Thermoelectricity*, 2, 71–78.
29. Anatychuk, L. I., Lysko, V. V., & Havryliuk, M. V. (2018). Ways for quality improvement in the measurement of thermoelectric material properties by the absolute method. *Journal of Thermoelectricity*, 2, 90–100.
30. Anatychuk, L. I., Lysko, V. V., Havryliuk, M. V., & Tiumentsev, V. A. (2018). Automation and computerization of measurements of thermoelectric parameters of materials. *Journal of Thermoelectricity*, 3, 80–88.

Надійшла до редакції: 10.05.2024.