TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO

1-B/2016

DOI: 10.4467/2353737XCT.16.067.5416

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# POWER GENERATION IN SMALL HEAT SOURCES USING THERMOELECTRIC GENERATORS

# WYTWARZANIE ENERGII ELEKTRYCZNEJ W MAŁYCH ŹRÓDŁACH CIEPŁA PRZEZ ZASTOSOWANIE GENERATORÓW TERMOELEKTRYCZNYCH

A b s t r a c t

This paper presents the results of studies conducted to determine the possibility of generating power using stove-fireplace with accumulation. During studies described in the paper, thermoelectric generator with the nominal power of 10 W and maximum operation temperature of 150°C was tested. Obtained results allowed to define real performance of the used generators. However, further tests are still needed to obtain better energy efficiency of the tested micro-scale cogeneration system.

*Keywords*: *microcogeneration, stove-fireplace with accumulator, thermoelectric generators, biomass*

S t r e s z c z e n i e

Artykuł prezentuje wyniki badań przeprowadzonych na potrzeby określenia możliwości wytwarzania energii elektrycznej z wykorzystaniem piecokominka. W czasie prowadzonych badań wykorzystany został moduł termoelektryczny o mocy 10 W, który charakteryzował się maksymalną temperaturą pracy równą 150°C. Otrzymane wyniki pozwoliły ocenić rzeczywistą wydajność zastosowanego generatora, a także wyciągnąć wniosek, że konieczne są dalsze testy dla uzyskania lepszej wydajności energetycznej stworzonego układu.

*Słowa kluczowe*: *mikrokogeneracja, piecokominek, generatory termoelektryczne, biomasa*

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## 1. Introduction

Micro-scale cogeneration systems, using heat generated in the boilers and other small heat sources, are going to be more and more popular in the near future. From currently recognized technologies (including Stirling engines, ORC based systems and thermoelectric generators), thermoelectric generators (TEG) were introduced to the tests.

The stove-fireplace with accumulation (SFA), which is a combination of fireplace and traditional accumulative stove, was used as a heat source. During typical operation, heat produced as a result of wood combustion is stored in the accumulative heat exchanger and dissipated up to 12 h after the fire has died out. As a result, the thermal efficiency of SFA can achieve a level of 90% [1].

The overall SFA efficiency can be further improved by the use of a dedicated power generating system. Such system may provide self-sufficient operation of the SFA and generate additional power used by home appliances or sold to the grid.

## 2. State of the art

The possibility of the use of thermoelectric generators in the small heat sources (including various types of stoves), is a subject of many worldwide studies. Nuwayhid et al. have presented the power generating system fitted to the side of a domestic woodstove and cooling by natural convection with maximum steady state matched load power 4.2 W (per single module) [2]. They have also studied the possibility of continuous generating 10–100 W electric power using of the heat from 20 to 50 kW wood stoves [3]. Lertsatitthanakorn investigated the similar prototype based on the biomass cook stove, getting a power output of 2.4 W [4]. As opposed to air cooling systems, Rinalde et al. [5] studied a forced water cooling system. In this case, an electric heater was used as a heat source and maximum power was obtained at the level of 10 W. In [6] there were compared a study of temperatures and electrical power measurements to a theoretical analysis using thermoelectric and heat transfer equations. More advanced studies were performed in [7], where TE modules manufactured with different materials have been tested. The power generator assembled with 96 TEG modules had an installed power of 500 W at a temperature difference of around 200°C, and an output power of about 160 W at a temperature difference of 80°C. Champier et al. has presented design and build a TE generator with $Bi_2Te_3$ modules which allows to operate with the maximum hot-side temperature at 230°C. TEG were fitted to the 10 kW cooking stove. Two cooling systems were tried: a heat fins exchanger placed on the cold side with a 10 W air fan and a water tank put directly on the cold side of the TE module. The maximum power reached between 1.7 W and 2.3 W per TE module for a temperature difference at a level of 160°C [8].

Analysis of the literature sources (above mentioned and other, connected e.g. with economic reasons) confirms the validity of the further studies in the area of the using thermoelectric generators in microcogeneration systems. This paper is related to the use of stove-fireplace with accumulation, but the proposed solution may be implemented also in the case of other heating appliances (e.g. biomass-fired boilers, fireplaces or stoves).

## 3. Test rig

The test rig used in the studies is equipped with a stove-fireplace with accumulation. The construction of SFA includes a furnace with a mass of 550 kg and the accumulation exchanger with a mass of 1050 kg. Based on the previously conducted tests, the starting version of dedicated heat exchanger dedicated for thermoelectric generators was located in the vicinity of the exhaust outlet from the furnace area [9]. The scheme of the studied system is shown in Fig. 1.

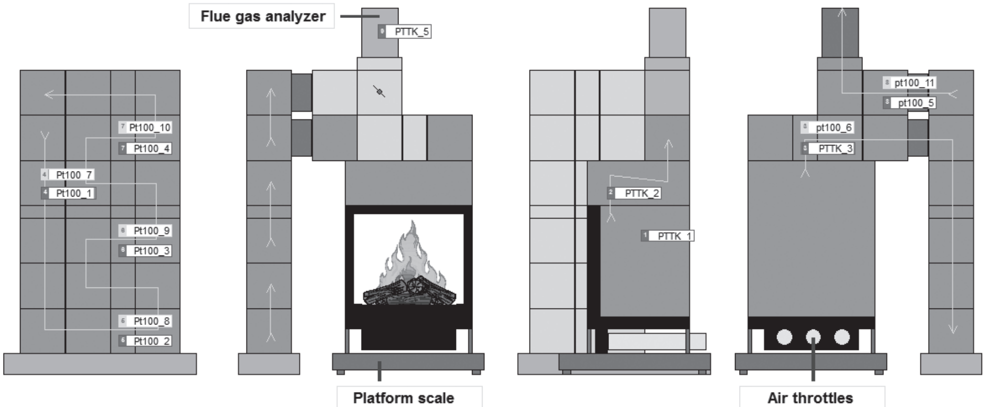


Fig. 1. The overview scheme of the studied system with marked heat exchanger for thermoelectric generators

Thermocouple and resistance sensors, monitoring temperature in the test rig, were located in the furnace area, in the flue gas channel, on the surface of the accumulation heat exchanger and on the surface of special heat exchanger designed for TEG. Besides temperature, there were performed the measurements of the flow rate of the air blown into the furnace area, the weight loss of fuel during the combustion process and concentration of the flue gas. The flue gas analyser uses the electrochemical methods for measuring the $O_2$ concentration (scope of 0–21%) and the NDIR method both for measuring CO (scope of 0–100 000 ppm), $CO_2$ (scope of 0–20%), NO (scope of 0–2500 ppm), $NO_2$ (scope of 0–500 ppm) and $SO_2$ concentrations (scope of 0–1000 ppm). Moreover, the $NO_x$ concentration is calculated. Combustion process is regulated using three air throttles controlled by analogue signals 0–10 V and flue gas throttle targeting the gas either to the chimney or to the accumulator exchanger or to the exchanger area with TEG. Measurements are recorded by the control and measurement system with the PLC controller [10].

Power generating system is equipped with a single $Bi_2Te_3$ module with the dimensions of 40 × 40 × 3.2 mm and maximum operation temperature at a level of 150°C. The tested thermoelectric module was placed on the surface of the heat exchanger. Cooling down was carried out using the dedicated water cooler, supplied with water at temperature of 10°C. The generated electricity was used for charging the battery (using the voltage controller).

## 4. Experimental results

### 4.1. Optimization of structure of heat exchanger dedicated for TEG

The first part of the conducted tests was devoted to study the operation parameters of two variants of the heat exchanger structures. First, simple structure was made in the form of a rectangular channel with an uninterrupted gas flow (see Fig. 2a). The result of large cross-section of the channel and the lack of external isolation was relatively low temperature of the exchanger's surface. Due to mentioned disadvantages, the structure of the exchanger has been supplemented by a constriction and a radiator (see Fig. 2b). The constriction allowed to increase the gas flow in the boundary layer and the radiator allowed to intensify the heat exchange between exhaust gas and exchanger's wall. This way, the surface of the heat transfers through gas to the exchanger surface got increased. Moreover, the 5 cm layer of mineral wool thermal insulation was applied.

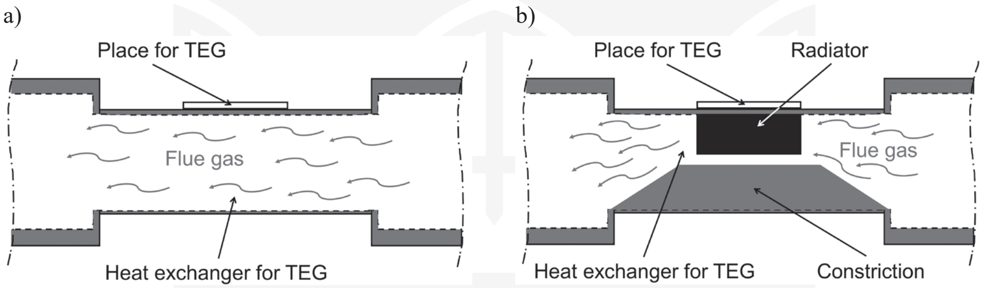


Fig. 2. Two variants of construction of the heat exchanger dedicated for TEG

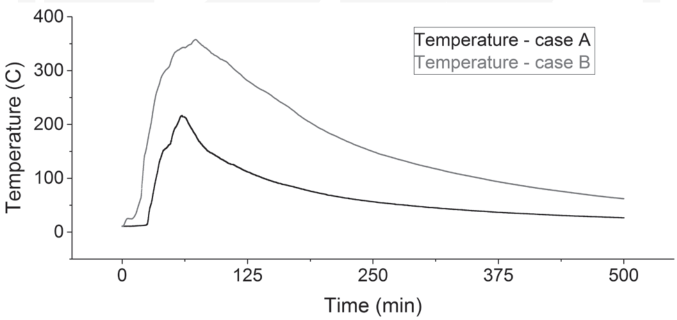


Fig. 3. Temperature variations on the exchanger's surface during combustion process

The temperature changes presented in the Fig. 3 were measured in the place of the destined assembly of the TEG (top wall of the exchanger) using a resistance temperature sensor Pt100. In each series 12 kg of dry pine wood was burned. To ensure identical process conditions, only one throttle of the supply air was fully opened, while the other dampers were closed.

The temperature variations on the exchanger's surface in each case tested is presented in Fig. 3. It can be concluded, that using additional elements (like constriction and radiator) allows to ensure significantly higher temperature on the exchanger's surface.

### 4.2. The study of TEG operation

The operation parameters of the thermoelectric generator (voltage, current and power), depend on the temperature of the hot and cold side. During conducted studies, the effect of the hot side temperature variations on the current-voltage characteristics and the obtained power has been experimentally determined. The increase of temperature of cooling water during TEG operation was less than 6 K (with the flow rate of 5 l/min). The studies were conducted using the artificial electronic load. The voltage-current characteristics, presented in Fig. 4, illustrates the increase of the open circuit voltage, short-circuit current as well as both of voltage and current with the increase of the exhaust gas temperature.

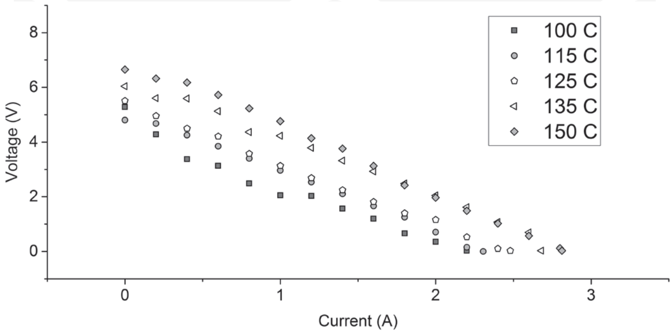


Fig. 4. Voltage-current characteristics of the tested thermoelectric generator

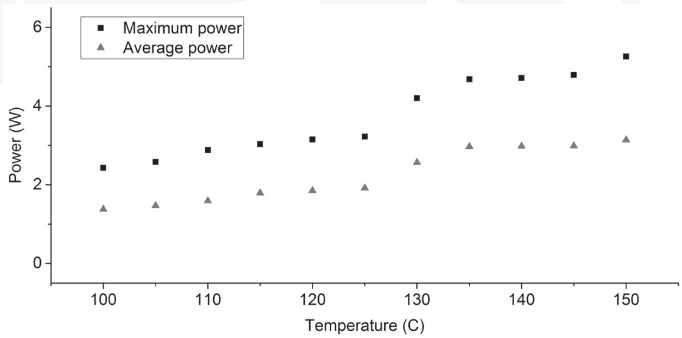


Fig. 5. Variations in the power value taken from TEG in the function of temperature

The high dependence on the temperature variations presents Fig. 5. This figure shows the variations in the power value taken from the thermoelectric generator in the function of the temperature (only the maximum power values were taken into account). The analysis of the presented data indicates the need to ensure the possibly constant parameters of exhaust (temperature, flow) during the combustion process.

## 5. Conclusions

Conducted tests confirm the possibility of using thermoelectric generators to generate power from the stove-fireplace with accumulation. During performed works only a single TE module was tested, however connecting few modules allows to achieve higher power and sufficient level of current and voltage. The proposed solution may be implemented also in the case of other heating appliances (e.g. biomass-fired boilers, fireplaces or stoves).

Analyzing results achieved during conducted tests we can conclude, that improvements in the power generating system construction are needed (e.g. in the area of intensification the heat transfer from flue gas to the hot side of TEG). When these changes are introduced to TEG operation, it will be possible to provide self-sufficient operation of stove-fireplaces with accumulation.

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*The work has been completed as part of the statutory activities of the Faculty of Energy and Fuels at the AGH "Studies concerning the conditions of sustainable energy development".*

## References

[1] Kurcz L., Filipowicz M., Sornek K., Szubel M., Rzepka K., Ręka J., *Źródła ciepła małej mocy w systemach ogrzewania Część 1. Piecokominki – aspekty techniczne, ekonomiczne, ekologiczne i estetyczne*, Ciepłownictwo Ogrzewnictwo Wentylacja, 46, 2015, 104–111.

[2] Nuwayhid R.Y., Shihadeh A., Ghaddar N., *Development and testing of a domestic woodstove thermoelectric generator with natural convection cooling*, Energy Conversion and Management, 46, 2005, 1631–1643.

[3] Nuwayhid R.Y., Rowe D.M., Min G., *Low cost stove-top thermoelectric generator for regions with unreliable electricity supply*, Renewable Energy, 28, 2003, 205–222.

[4] Lertsatitthanakorn C., *Electrical performance analysis and economic evaluation of combined biomass cook stove thermoelectric (BITE) generator*, Bioresource Technology, 98, 2007, 1670–1674.

[5] Rinalde G.F., Juanicó L.E., Taglialavore E., Gortari S., Molina M.G., *Development of thermoelectric generators for electrification of isolated rural homes*, International Journal of Hydrogen Energy, 35, 2010, 5818–5822.

[6] Champier D., Bédécarrats J.P., Kousksou T., Rivaletto M., Strub F., Pignolet P., *Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove*, Energy, 36, 2011, 1518–1526.

[7] Liu Ch., Chen P., Li K., *A 500 W low-temperature thermoelectric generator: Design and experimental study*, International Journal of Hydrogen Energy, 39, 2014, 15497–15505.

[8] Champier D., Bedecarrats J.P., Rivaletto M., Strub F., *Thermoelectric power generation from biomass cook stoves*, Energy, 35, 2010, 935–942.

[9] Filipowicz M., Kurcz L., Sornek K., Szubel M., Ręka J., *Pomiary podstawowych parametrów pracy piecokominków*, Instal, 6, 2014, 26–33.

[10] Sornek K., Szubel M., Goryl W., Bożek E., Filipowicz M., *Possibilities of generation and use of energy from biomass*, Przemysł Chemiczny, 12, 2014, 2071–2076.