

AUTOMATIC BIOMASS BOILER WITH AN EXTERNAL THERMOELECTRIC GENERATOR

MARIAN BRÁZDIL*, LADISLAV ŠNAJDÁREK, PETR KRACÍK, JIŘÍ POSPÍŠIL

Brno University of Technology, Faculty of Mechanical Engineering, Energy Institute, Department of Energy, Technická 2896/2, 616 69 Brno

* corresponding author: brazdil@fme.vutbr.cz

ABSTRACT. This paper presents the design and test results of an external thermoelectric generator that utilizes the waste heat from a small-scale domestic biomass boiler with nominal rated heat output of 25 kW. The low-temperature Bi₂Te₃ generator based on thermoelectric modules has the potential to recover waste heat from gas combustion products as effective energy. The small-scale generator is constructed from independent segments. Measurements have shown that up to 11 W of electricity can be generated by one segment. Higher output power can be achieved by linking thermoelectric segments. The maximum output power is given by the dew point of the flue gas. The electrical energy that is generated can be used, e.g., for power supply or for charging batteries. In the near future, thermoelectric generators could completely eliminate the dependence an automated domestic boiler system on the power supply from the electricity grid, and could ensure comfortable operation in the event of an unexpected power grid failure.

KEYWORDS: Thermoelectric generator, thermoelectricity, waste heat, biomass boiler.

1. INTRODUCTION

Automated small-scale domestic pellet boilers offer high efficiency and a comfortable form of a residential heat supply. Their numbers on the Czech market, and also the consumption of wooden pellets, have been rising gradually and these boilers are progressively replacing old combustion equipment. This situation is favourable from the point of view of environmental protection and air pollution. New automated boilers meet the requirements of emission standards.

However, incorporating unstable renewable sources into the energy mix, and also insufficient transfer capacity, has led to some fluctuations in the electricity grid. These situations, which may be caused by some unstable renewable sources, are scarcely predictable, and may result in disintegration of the grid or in island operation [1]. Although blackouts may not necessarily occur, their probability will increase in the future. Electric power interruptions may also occur due to defects on obsolete electricity devices, or due to mechanical damage to electricity distribution mains caused, for example, by natural disasters, lightning strikes on a transformer power station, etc. On the one hand, new automated electrical equipment is being introduced that eliminates the intervention of operators. On the other hand, sudden power interruptions may occur that are absolutely essential for this equipment and also for its operators. Combustion equipment can be secured against short-term power interruptions by using a stand-by power supply with accumulators. However, capacity of this equipment is not sufficient for long-term interruptions.

Thermoelectric generators (TEG) based on thermoelectric effects can directly convert thermal energy into

electricity. These solid state devices can utilize, e.g., flue gas low-temperature waste heat from small-scale pellet boilers or wood stoves, to produce useful electrical energy [2]. During operation, it would be possible to generate electric power for self-consumption with a small-scale thermoelectric generator (water pump supply, fan and control unit supply), or the generated electric power could be stored in batteries for future utilization (fire ignition) [3]. Transfer of the waste heat would enable a better fuel economy and reduced electric power consumption. The domestic small-scale TEG was designed, constructed and tested to investigate the options for transforming waste heat into electricity. This device can be connected to a current combustor without the need to intervene in its construction.

2. EXPERIMENTAL PROCEDURES

2.1. CONSTRUCTION OF THE PROTOTYPE

The experimental thermoelectric system is shown in Fig. 1. The system consists of a biomass boiler, a designed segment of TEG with thermoelectric modules, a flue gas duct, two plate heat exchangers, an electric water heater, and a large water storage tank. The nominal rated heat output of an applied automatic biomass boiler is 25 kW. The temperature of the flue gas in the boiler outlet exceeds 200 °C. First, the industrially-available low-temperature Bi₂Te₃ TE modules TEG-127-230-32e were selected and tested, and then the modules were replaced by more powerful TE modules TG 12-6-01L (Marlow Ind., USA), also made of bismuth telluride. These modules have dimensions of 44.7 × 40.1 × 3.9 mm. They can withstand



FIGURE 1. Thermoelectric biomass boiler test-system assembly.

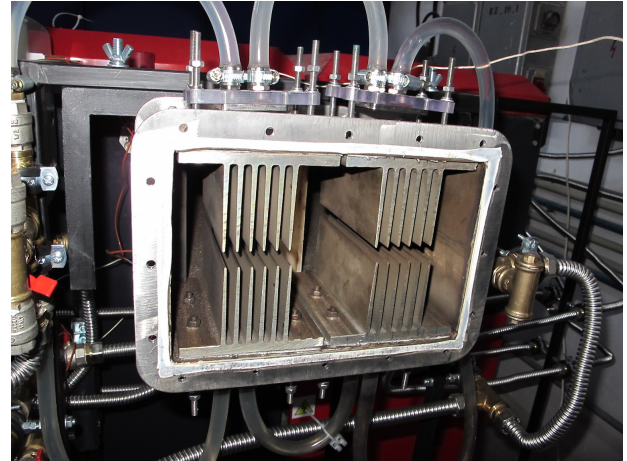


FIGURE 2. Design of the TEG segment.

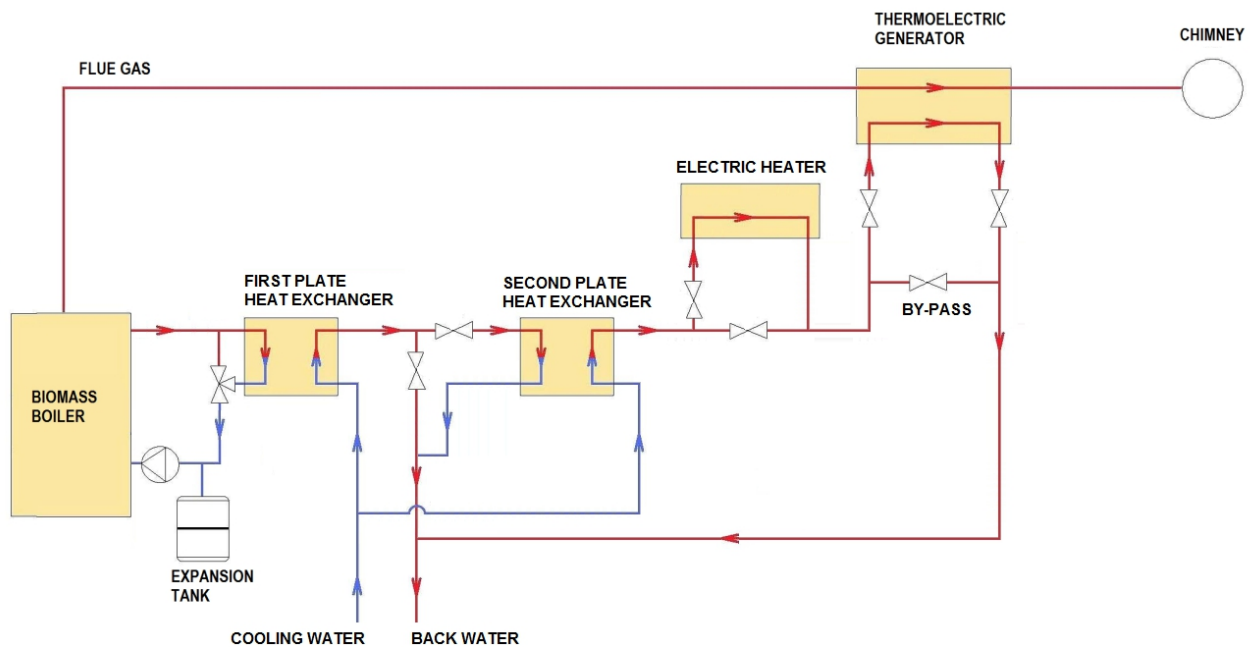


FIGURE 3. Scheme of the proposed thermoelectric system.

continuous operation below 200 °C, and intermittent operation up to 250 °C. The internal resistance of one module is approx. $2\ \Omega$, the nominal power output is 6 W, and the value of the figure of merit which quantifies the potential to convert heat to electricity $ZT = 0.73$. One segment of the TEG (Fig. 2) consists of four TE modules, which are placed around the segment between the hot-side aluminium heat sinks and the cold-side copper water cooling blocks. The body of the segment and also the gas duct are made of stainless steel.

The heat is conducted to the TE modules by the flue gas flowing through a flue gas duct. It is partly transformed into electric power inside the modules, and the rest of the heat is conducted away through the

cooler circuit. This preheats the water flowing into the boiler, and the generator therefore also functions as an economizer.

2.2. EXPERIMENTAL SETUP

A diagram of the measurement track is presented in Fig. 3. The heated water from the boiler flows inside a closed circuit with a plate heat exchanger, where the heat is transferred to the cooling loop. In practical applications, the cooling of the generator might be arranged by the boiler back water. In order to avoid low temperature corrosion of the boiler heating surface, its temperature before the boiler input should be not lower than 60 °C. To simulate real operating conditions, it is therefore necessary to change

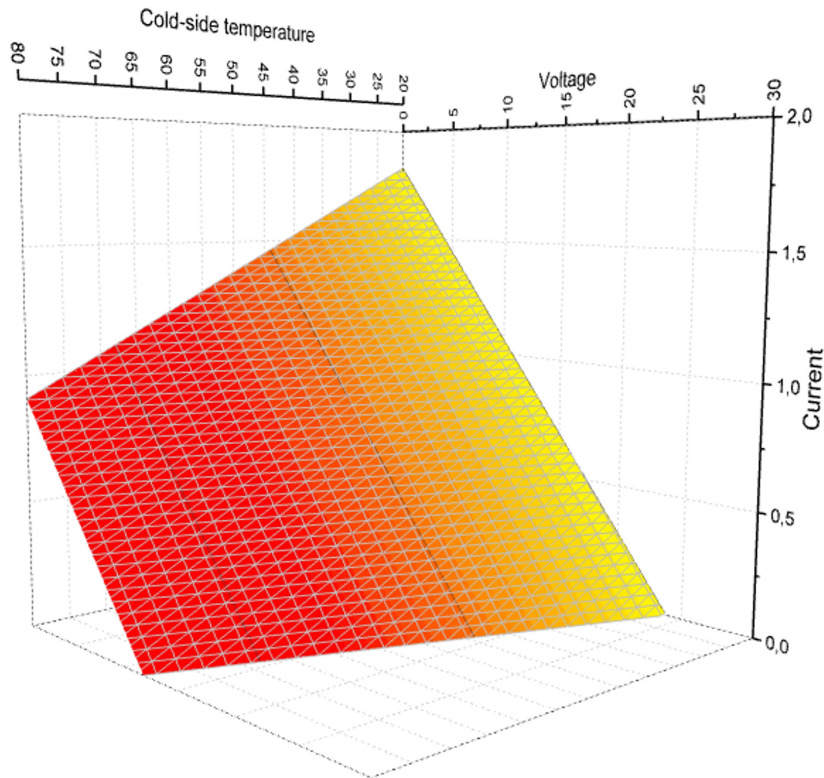


FIGURE 4. Voltage versus current at various cold-side temperatures.

the temperature of the cooling liquid flowing into the generator. The heated cooling water flowing from the plate heat exchanger is used for this purpose. It preheats the cooling water flowing into the generator through the second plate heat exchanger, and thus simulates the variable TE modules cold-side temperature. An electric circulating water heater that heats the cooling liquid as required is additionally connected to the circuit.

3. MEASUREMENTS

Advantech data acquisition modules 4017 and 4018+ were used for the temperature and open-circuit voltage measurements. The temperature of the cooling loop water, the TE modules hot-side temperature, and the temperature of the flue gas in front of the segment and behind the segment were measured by K-type thermocouples. The cooling liquid flow rate for the generator is maintained at an approximately constant value of 5.8 L/min, and the water temperature is gradually increased. The TE modules were connected electrically in series, in parallel and in series-parallel combination. The measurements of performance characteristics of the generator were carried out in the following sequence: The boiler was heated from a low temperature to the rated heat output, and then the boiler was shut down and cooled. The performance parameters were measured during this period. Open-circuit voltage was generated by the heat flow through the modules, and it was recorded. Performance was

generated after connecting the modules at a variable resistance load. The relevant voltage values and currents were recorded, and are presented in the following graphs.

4. RESULTS AND DISCUSSION

The measurements imply that maximum performance was reached by the thermoelectric generator in the serial-circuit connection. This type of connection was further measured in detail for the voltage and current course in relation to the TE cold-side temperature at maximum inlet flue gas temperature 196 °C (Fig. 4). The power output decreases with increasing cooling liquid temperature (i.e. TE cold-side temperature). The maximum measured output power reached 11 W. Measurements show that flue gas temperature drops significantly after flue gas has flowed through the segment. The maximum temperature difference between the inlet and outlet section of the generator is approx. 23 °C. It follows that higher output can be achieved by linking the thermoelectric segments together until the flue gas temperature in the flue gas duct drop below the dew point, otherwise there would be low-temperature corrosion and damage to the flue gas duct. Adding insulation to the generator will also increase the flue gas temperature and the power output of the generator.

The major disadvantage of the proposed TEG is its low energy efficiency. Applied TE modules have quite a low value for the figure of merit ZT (< 1).

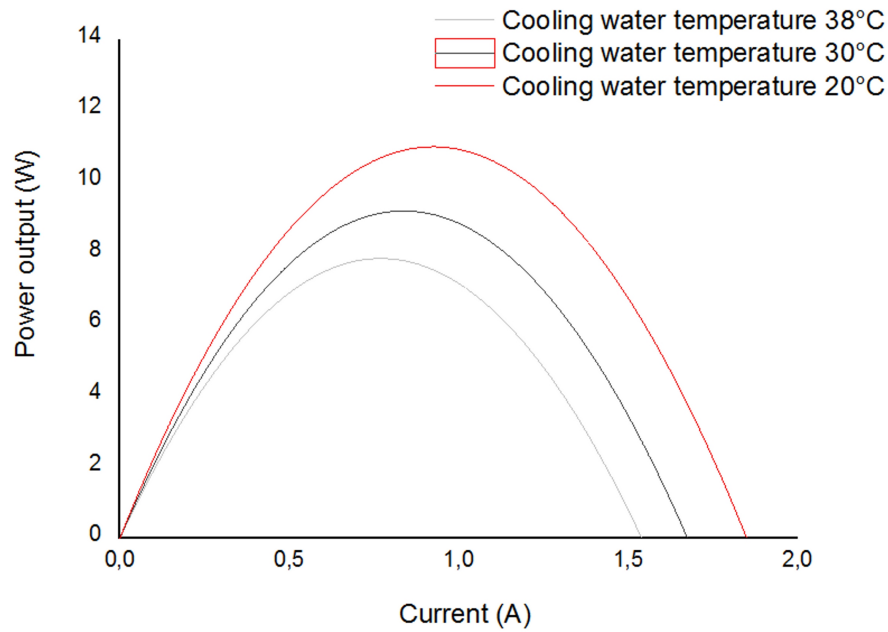


FIGURE 5. Output power versus current at various cold-side temperatures.

The thermoelectric power generation efficiency can be increased significantly by placing modules close to the combustion chamber, where the temperature of the flue gas is higher. It would, however, be necessary to incorporate thermoelectric modules into the boiler system, and to use thermoelectric modules which can operate under the higher temperature, for example modules made of PbTe or TAGS materials, or segmented thermoelectric modules which are, however, not yet industrially available.

ACKNOWLEDGEMENTS

This work was financially supported by the Brno University of Technology under Grant SVV-2012-FSI-S-11-7.

REFERENCES

- [1] CIESLAR, S.: Island operation — a solution for the future, *All for Power*, 2012, Volume 4, pp. 119–120
- [2] HÖFTBERGER, E., MOSER, W., AIGENBAUER, W., FRIEDL, G., HASLINGER, W.: Grid autarchy of automated pellets combustion systems by means of thermoelectric generators, *Bionenergy2020+* [online]. 2010, 26 pp. <http://www.bioenergy2020.eu/files/publications/pdf/I1-2481.pdf> [2013-04-15]
- [3] QIU, K., HAYDEN, A.C.C.: Development of thermoelectric self-powered heating equipment, *JEMS*, 2011, Volume 40, pp. 606–610.