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Cogeneration Unit for Small Stove

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Abstract**—**This paper shows an experimental testing of a small unit for combustion of solid fuels, such as charcoal and wood logs, that can provide electricity. One of the concepts is that the unit does not require qualified personnel for its operation. The unit itself is composed of two main parts. The design requires a heat producing stove and electricity producing thermoelectric generator. After the construction the unit was tested and the results show that the emission release is within the legislative requirements for emission production and environmental protection. That qualifies such unit for indoor application.

Keywords**—**Micro-cogeneration, thermoelectric generator, biomass combustion, wood stove.

I. Introduction

RECENTLY, there has been an increased interest in use of thermoelectric generators. Their benefits include simplicity, reliability, and long service life. The generators have no moveable parts and they do not contain any chemical components and they are also environmentally friendly [1]. Current trends of environmental protection together with fuel prices and demand for environmentally friendly technologies make application of thermoelectric equipment an interesting option which enables generation of electricity from waste heat [2].

This paper researches a design of small-scale combustion equipment (a wood stove) with a thermoelectric generator which may in future serve as a small-scale micro-cogeneration unit [5]. Benefits of the micro-cogeneration unit include use of a waste heat for heating of water (and a subsequent residential heating) together with the generation of high-quality electrical energy that may be used in various other applications. Our research work further aims to assess the impact of the thermoelectric generator on the wood stove. Latest work in the area of environmental protection shows that the future of technologies for combustion of solid fuels is a path of elimination of the service personnel whose actions have a negative impact on the quality of the combustion process and thus decreasing the total negative impact of small scale combustion units [4].

II. Experimental Procedures

A. Construction of the Prototype

The micro-cogeneration unit itself is composed of two components, i.e. the combustion unit and the thermoelectric generator. Heat energy in the combustion unit is released from combustion of wood logs in a closed local furnace (Fig. 1). The combustion chamber of the furnace is not isolated from surrounding environment; certain amount of heat is transferred into its surroundings. The combustion chamber has been designed with respect to the latest requirements on emission levels and unit efficiency, including amendments to the law addressing the air protection. Various measures have been taken to secure compliance with the law. The most significant steps taken to maintain proper functioning of the device included suitable geometry design of the combustion chamber, layering of combustion air and amount and temperature of the combustion air. A jet of a tertiary preheated combustion air is located directly below the deflector where flue gas flows in with great velocities and where is a sufficient temperature for burning out of incomplete combustion products. An adequate positioning of particular heat exchangers is the key factor in the equipment design that prevents premature cooling of the flue gas and the formation of undesired emissions.

Fig. 1 Cogeneration unit

B. Thermoelectric Generator

By theory, the thermoelectric generators are using Seebeck effect to directly convert heat into voltage and therefore electricity. The construction of one thermoelectric generator module consists of serial connected P and N semiconductors pellets placed between ceramic plates (Fig. 2). The main advantage is that these modules do not contain any moving parts. But they still have major disadvantages as they provide only few watts of electric power and sufficient efficiency appears only at high temperature differences (more than 200°C).

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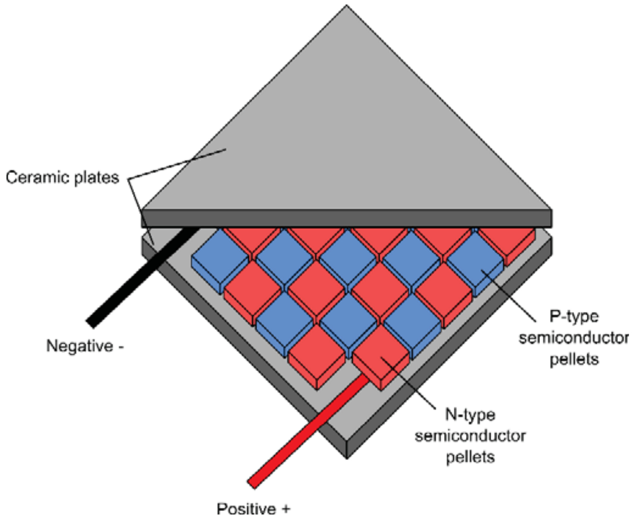

Fig. 2 Design of construction of one thermoelectric generator module

The thermoelectric generator (Fig. 3) used in the micro-cogeneration unit consists of two heat exchangers and ten low-temperature serial connected bismuth telluride thermoelectric modules TG 12-6-01L (Marlow Ind., USA). These modules have dimensions of 44.7×40.1×3.9 mm. They can withstand continuous operation below 200 °C, and intermittent operation up to 250°C. The internal resistance of one module is approx. 2 Ω, the nominal power output is 6 W and the value of the figure of merit which quantifies the potential to convert heat to electricity is ZT = 0.73. The hot side of the generator is made from a ribbed aluminum plate and the cold side is made from ribbed copper plate. A flue gas heat exchanger (hot side) leads the heat from the flue gas to the thermoelectric modules; a cooling heat exchanger (cold side) transfers heat to the cooling loop and thus preheats the water entering the hot-water heat exchanger (Fig. 5).

C. Wood Stove

The wood stove used in this application has a nominal power output of 12 kW and is designed for indoor use. The materials are cast-iron plating and inside is a fire clay lining. The fuel is combusted on a horizontal non-cooled grate and is hand feed through a glass door. The primary air is not preheated and enters the stove under the grate and partially combusts the fuel. For a more effective combustion the non-preheated secondary air enters the stove from above the glass door and is forced to go down alongside the glass, working as a glass rinsing agent. To ensure an enhanced combustion efficiency, the tertiary air that is preheated enters the stove from the opposite side of the glass door and goes upwards between the iron-cast plating and the fire clay lining (Fig. 4).

The combustion equipment includes a flue gas damper which prevents the impairment of the thermoelectric modules due to the high operational temperatures and restrains the reduction of modules service life due to sudden temperature changes. The damper is located in a deflector and is powered by a servo-drive. Based on a temperature of the flue gas passing through the thermoelectric generator and the temperature of the flue gas passing through the water heat exchanger, the damper distributes flue gas flow between the heat exchanger with the thermoelectric modules and the hot-water heat exchanger.

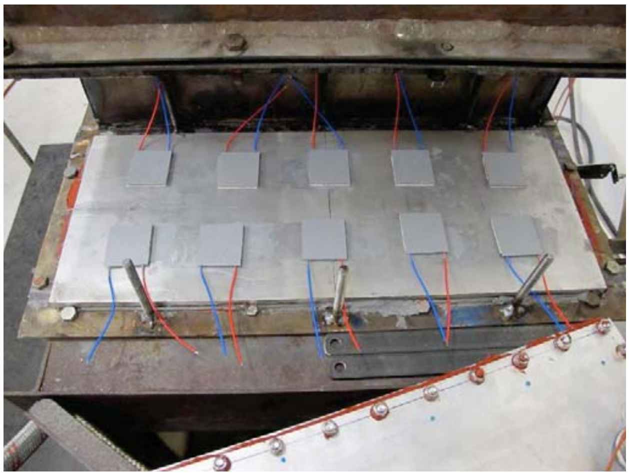

Fig. 3 Components of the thermoelectric generator

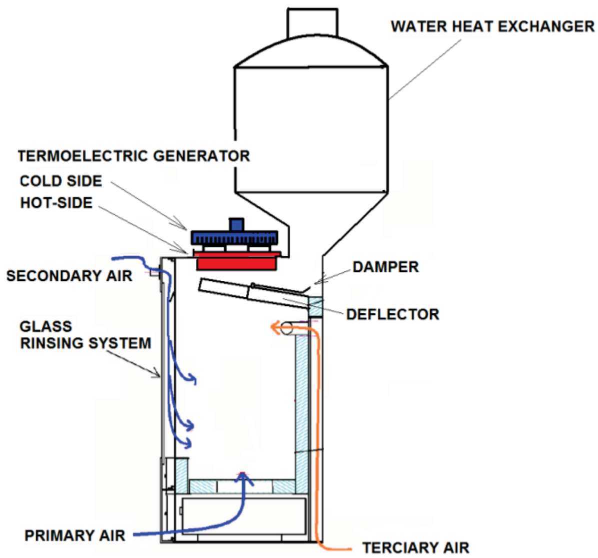

Fig. 4 Design of the proposed unit

When the unit is in operation, flow of the hot flue gas leaves the combustion chamber and is directed by the deflector. The heat exchanger with the thermoelectric modules is located beyond the deflector (Figs. 3, 4). The electrical energy is generated after the heat has been transferred in the thermoelectric modules. The flue gas subsequently passes through the hot-water heat exchanger which cools the flue gas to 160°C and then leaves through a flue way to a stack vent. Concerning the integration of the hot-water circuit, the equipment is designed to first withdraw heat from the cold side of the thermoelectric modules (so that the highest heat difference between the cold and the hot side of the generator is

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achieved). Thus the heating water is preheated and later enters into the hot-water fire-tube heat exchanger.

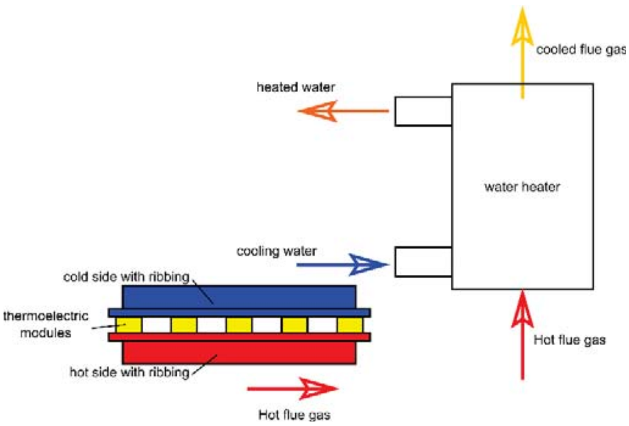

Fig. 5 Thermoelectric generator operation

D. Experimental Setup

The experimental part of this work was divided into two sections. The first part deals with measurement activities at the combustion unit itself (efficiency, heat output to the air, heat output to the water and emission measurements). The second part deals with capacity characteristics of the assembled thermoelectric generator.

III. Measurements

The combustion equipment was tested according to the ČSN EN 13229 standard – Inset appliances including open fires by solid fuels – Requirements and test methods. The efficiency is determined by using the indirect method in this standard. Particular losses are deducted from maximum total (100 %): the loss due to unburned fuel, the loss due to incomplete combustion and the loss due to the sensible heat of the flue gas. The measurements were performed at a measurement site which is equipped with scales for online measurement of the fuel weight loss, a cooling loop for measurement of the amount of heat exchanged via the hot-water heat exchanger, thermometers and flue gas analyzers for a measurement of a particular components concentration.

In the second part of our work, we tested the thermoelectric generator. The generator was attached to a resistance load and its capacity was measured in dependence with temperature.

IV. Results

The calculations and measurements were carried out according to the ČSN EN 13229 standard. The measured and calculated values are given in Table I.

By measuring the thermoelectric generator, we found out that the maximum electrical power output of the generator equals 21 W. Since the nominal heat capacity of one module reaches roughly 6 W and the capacity is much lower than expected (60 W), we also measured the change of the open-circuit voltage for the individual modules (Fig. 6).

TABLE I
Boiler Parameters

Symbol	Quantity
Efficiency	86 %
Total power output	12.2 kW
Power output to water	3.8 kW
Mass flow of the fuel	3.2 kg/h
CO concentration	820 ppm/10 % O_2
CO_2 concentration	9.2 %
Leaving flue gas temperature	162 °C

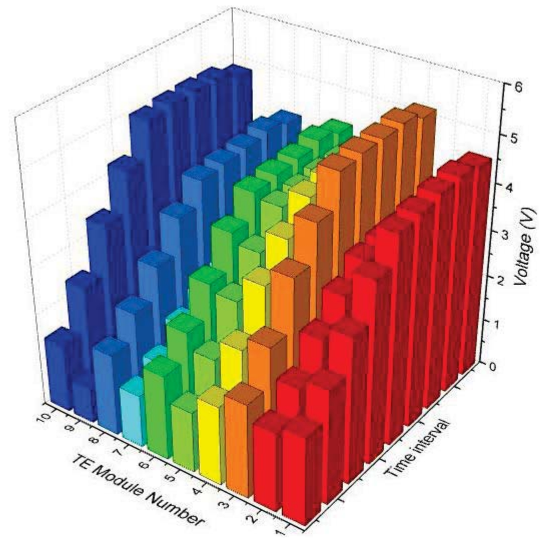

Fig. 6 Open-circuit voltage for individual thermoelectric modules

V. Discussion

The measurement revealed that application of a tertiary jet, which leads the preheated combustion air into the combustion chamber, is useful. The benefits of the jet are more obvious when the combustion equipment works with a minimum capacity and the slide valves for supply of the primary air under the grate and the slide valves for supply of the secondary air for glass rinsing are almost closed. The amount of air flowing in the jet is limited by the jet outlet holes only; in other words, it is not dependent on the location of the slide valves of the primary and secondary combustion air. This arrangement greatly eliminates the negative impact of personnel on the quality of the combustion process. The hot-water heat exchanger is positioned as the last heat transferring surface and this location has a positive impact on the temperature of the outlet flue gas and thus also on the efficiency of the whole equipment without the occurrence of a premature flue gas cooling and the formation of undesired emissions.

The measurements of the electrical characteristics of the thermoelectric generator prove that the total power output of the generator is immensely degraded by different output power of particular modules. This is caused by uneven temperature field of the hot side and the cold side of the generator. This uneven distribution causes various temperature differences on the individual modules and therefore affects their electrical parameters, as the measurements of the open-circuit voltage show (Fig. 6). This factor mostly depends on the conditions inside and outside of the combustion equipment, on the generator design (a poor heat contact caused by the imperfect flatness of the flue gas heat exchanger and the cooling heat exchanger area) and also on manufacturing flaws of the particular thermoelectric modules. The potential for reducing the creation of uneven temperature distribution and the enhancement of the generator capacity will be the subject of a further research. A recent study shows that enhancing the heat transfer coefficient and a multiple-stage thermoelectric generator may yield enhanced results [3].

Acknowledgment

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References

[1] D. M. Rowe, "Thermoelectric waste heat recovery as a renewable energy source," *International Journal of Innovations in Energy Systems and Power*, 2006, Volume 1.

[2] W. He, G. Zhang, X. Zhang, "Recent development and application of thermoelectric generator and cooler," *Applied Energy*, 2015, Volume 143.

[3] X. Liang, X. Sun, H. Tian, "Comparison and parameter optimization of a two-stage thermoelectric generator using high temperature exhaust of internal combustion engine," *Applied Energy*, 2014, Volume 130.

[4] S. van Loo, J. Koppejan, "Handbook of biomass combustion and co-firing," Twente University Press, 2002.

[5] OBERNBERGER, I.: Decentralized biomass combustion: state of the art and future development, 1998, pp. 33-56.