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EXPERIMENTAL STUDY OF RICE HUSK COOK STOVE INTEGRATED WITH THERMOELECTRIC POWER GENERTOR

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ABSTRACT

The use of a rice husk gasifier as a cook stove is limited to the domestic sector of developing countries primarily because it needs electrical energy to drive a blower for the gasification process. To solve this problem, we investigated the feasibility of attaching commercial thermoelectric (TE) modules made of bismuth–telluride materials to the gasifier's side wall, thereby creating a TE generator system that utilizes a proportion of the gasifier's waste heat. A rice husk gasifier TE generator (TE-RSG) having an internal diameter of 16 cm was fabricated and tested. The TE generator system consisted of six commercial TE modules, a metal sheet wall which acted as one side of the gasifier's structure and served as the hot side of the TE modules and a water-cooled heat sink at the cold side of the TE modules. A fan was used to suck the ambient air to the reactor of the gasifier. Gasification was conducted in a temperature range of 450-540°C and gasification agent, air feeding rate of 16.20-19.08 m3/h. The results revealed that the electrical power output and the conversion efficiency depend on the temperature difference between the cold and hot sides of the TE modules. At the temperature difference of approximately 117.4°C, the unit achieved a power output of 38.19 W and a conversion efficiency of 2.83%. The electrical power generated by the TE modules was enough to drive the blower of the rice husk gasifier and the water pump.

Keywords: Thermoelectric; Conversion efficiency; Power output

INTRODUCTION

There is a rising interest in methods to utilize biomass owing to the limited reserves of fossil fuels, regulations on CO2 emissions, and demand for reduced dependence on foreign energy. Biomass is one of the most important and most widely used renewable energy resources. There is, in particular, increasing need to utilize the energy from biomass wastes such as wood wastes and agricultural residues [1]. Rice husk, a type of biomass, is the major byproduct generated from the rice milling industry. In Thailand, where the average gross rice production is approximately 32.09 Mtons/yr., 6 Mtons of rice husk is produced and around 600 thousand tons of ash is generated by burning the rice husk [2]. Currently, rice husk is widely used in stall mats, compost and fillers. However, due to increasing demands for utilization of waste-to-energy, many researches are actively involved in research-ing ways to use rice husk as a fuel. Approxi-mately 2.4 billion people depend on wood, dung, charcoal and other biomass fuels for cooking. Most of these people cook on open fires that burn poorly leading to low thermal efficiency and high pollution emissions. The current patterns of use cause significant negative impact of several types, including human morbidity and mortality, outdoor air pollution, climate change and deforestation. One interesting alternative to these inefficient cooking methods is a rice husk gasifier; it is more efficient than biomass cook stoves [3]. However, electrical power is needed to drive a blower that is part of the rice husk gasifier system. Individual thermoelectric (TE) power generators coupled with rice husk gasifier offer an interesting option to provide electricity. Studies have been conducted in TE generators coupled with biomass stoves. As the examples, Nuwayhid et al. [4] considered the prospect of applying TE modules located on a wood stove-top to produce power. That system is well known and could be useful in regions with unreliable electricity supply. The stove-top TE system produces a maximum power output of 2.7 W per module. A heat sink composed of a thermosyphonic heat pipe has been adapted to further improve the power output of a TE module [5]. These developments revealed that a commercially available TE module could provide over 3 W of power with a temperature difference between the hot and cold side of the TE module of 70-80°C. Experiments have also been conducted on the side-walls of cook stove. Stove wall temperatures are likely to be in the range of 150-300°C. Lertsatitthanakorn [6] investigated a combined biomass cook stove thermoelectric (BITE) generator. The results of that investigation showed that the BITE produces a maximum power output of 2.4 W at a temperature difference of 150°C. The conversion efficiency of 3.2% was enough to drive a low power incandescent light bulb or a small portable radio. Meanwhile, the payback period of the BITE is 0.74 years if compared with batteries supplying power to a 1.8 W load with an annual operating time of 365 hours. Champier et al. [7] studied a TE generator incorporated in a multifunction wood stove to produce electrical power from the exhaust gas of the wood stove. One-dimensional heat flow was used to predict the system's performance. The TE module produced maximum power output of 9.5 W. An economic analysis showed that the price of TE modules varied with order volume. By comparison between the cost per watt of the PV panels and the TE generator, it was found that the cost per watt of the TE module is very competitive with PV panels. This work will consider the TE recovery of electrical power of a rice husk cook stove. Meanwhile, the heat sink interfaced on the TE cold side releases heat to the cooling water for generation hot water.

CALCULATING METHOD

The electrical output of the TE modules (P) is also calculated from the measured data as follows:

$$P = I \cdot V \qquad \text{...(1)}$$

Miller et al. [8] suggested that the conversion efficiency is as follows:

$$\eta_e = \eta_c \frac{M-1}{M+\frac{T_c}{T_h}} \qquad \text{...(2)}$$

where $M=\sqrt{1+ZT_m}$ which $T_m=0.5(T_h+T_c)$

Note that   is a characteristic parameter of the thermoelectric element and essentially governs its internal conversion efficiency. It is well known that the value of Z can have strong variations in temperature. In this study, in order to gain insight into the optimal collector operating temperatures, the value of Z is assumed to be constant. Although this may be an over simplification of the actual situation, it provides tractable solutions for the solar collector temperature and operating efficiency of the thermoelectric element.

η_c is is the Carnot efficiency; $\eta_c \frac{T_h-T_c}{T_h}$ …(3)

EXPERIMENTAL SET-UP

Fig. 1 illustrates the TE-RSG. As shown in Fig. 1, the TE-RSG is divided into three main parts: (1) the gasifier cook stove part, (2) the TE power modules part, and (3) the water cooling part. The gsifier was a batch fed up-draft gasifier. It basically consists of a reactor, a burner and a blower. The reactor is a concentric cylinder in tube having an inside tube diameter of 16.5 cm and a height of 100 cm. The reactor is made of 2 mm thick galvanized iron sheet. The outer cylinder has a diameter of 30 cm. An annular space between the inside and outside cylinder holds a ceramic fiber insulator to prevent heat loss from the reactor. The inner cylinder is fixed to the top flange. The flange, together with the inner cylinder, can be made removable from the outer cylinder for easy cleaning and replacement when worn out. At the lower end of the reactor inner cylinder is a fuel grate made of mild steel used to hold the rice husk during gasification. A fan is used to supply the air needed for gasification of rice husk. The air flow rate was varied in a range of 16.20-19.08 m3/h. In this experiment six TE power modules (TEHP1-12635-1.2, China) were used and connected in series. Metal steel was installed at the upper of the side of the reactor outer cylinder. The hot side of TE modules was fixed on the metal she. A water-cooled heat exchanger made of aluminum was attached directly to the cold side of TE modules. Fig. 2 shows the detail of the water-cooled heat exchanger. The cooling water in the storage tank pumped into the heat exchanger with a pump. The total volume of water in the storage tank was 15 L. In this study, the water flow rate was fixed at 17 L/min. Therefore, the pump consumed 18 W. The space between the TE modules, hot plate and heat sink was insulated using a locally made ceramic fiber.

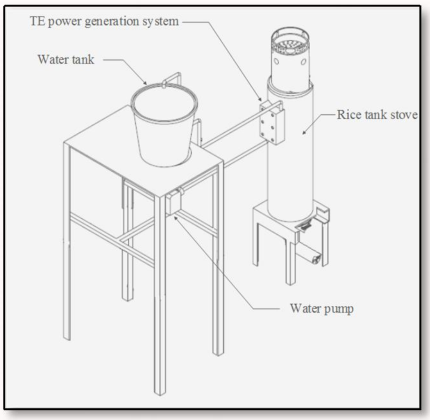

Fig.1 Schematic diagram of the TE-RSG

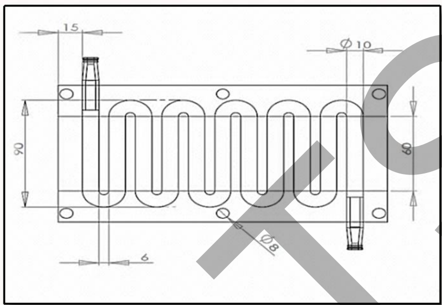

Fig. 2 Detailed figure of water-cooled heat exchanger

The gasifier was instrumented with K-type (accuracy ±0.5°C) thermocouples that measured the temperature of the hot side and the cold side of the TE modules and the gas. The thermocouple that measured the ambient temperature was kept in a shelter to protect it from direct sunlight. The current and voltage were measured with a multi-meter (Fluke model 189, accuracy VDC ±0.025%, A ±0.5%). Air velocity was measured by a hot bulb velocity probe (accuracy ±0.03 m/s) at the inlet of the air duct. A DC power supply was used to drive the blower.. A data acquisition system was used to collect the data at regular intervals every 1 minute.

RESULTS

Fig. 3 shows the variation of electric power output and the conversion efficiency with the exhaust gas (heat source) temperature. It is apparent that the electric power output and efficiency continued to increase as the exhaust gas temperature increased. The maximum power and conversion efficiency are 38.19 W and 2.83%, respectively, at an exhaust gas temperature of 540°C. The open-circuit voltage and short-circuit current are 22.6 V and 1.69 A, respectively.

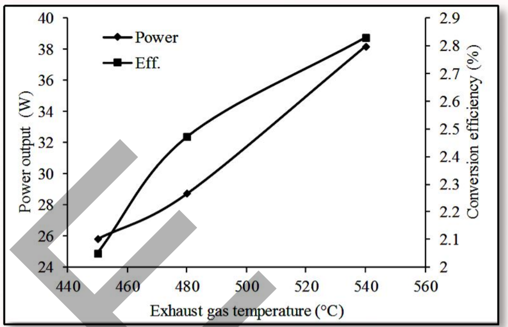

Fig. 3 Variations of power output and conversionefficiency with exhaust gas temperature

The water temperature is dependent on the exhaust gas temperature. It is due to the fact that as the exhaust gas temperature increases, the heat transfer trough the TE modules increase. Therefore, the withdrawal of heat also increases, which causes the increase in water temperature, as shown in Fig. 4.

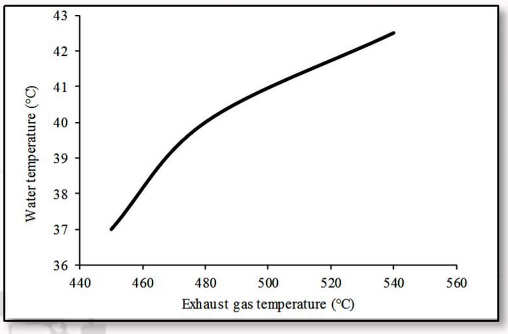

Fig. 4 Variation of water temperature with exhaust gas temperature

CONCLUSIONS

The experimental study on operation performances of the TE-RSG was conducted. During the entire operating period, the TE-RSG was stable. Under the test conditions used here, the maximum water temperature was 42.5°C and hot water capacity of 15 L. The TE modules generate electric power of 38.19 W at an exhaust gas temperature of 540°C. This generated power is enough to run some electric devices. Therefore, the experi-mental results indicate that the TE-RSG system has better performance.

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NOMENCLATURE

P Electrical output of the TE solar collector (W)
T_c Cold side temperature of TE module (K)
T_h Hot and cold side temperature of TE module (K)
T_m Average temperature (K)
V Voltage of the TE modules (V)
Z Figure of merit of the TE material (1/K)
η_c Carnot efficiency
η_e Conversion efficiency

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