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Effect of a thermoelectric circuit on DC electricity generated on the utilization of waste heat from the earthenware furnace

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ABSTRACT: Study on thermoelectric generator utilizing the waste heat from a traditional stove was conducted. This was due to villagers. People who live in remote villages could not have electrical power yet. The purpose of this study was to know the possibility of thermoelectric generators to produce electrical power. Three thermoelectric generators were used. The type of the thermoelectric generator was SP1848-27145 SA. The variations investigated were series and parallel with and without load. The load employed was a thermoelectric cooler type TEC-12706. The results showed that in testing without thermoelectric generators, the heat loss to the environment was 2037 W, while that using a thermoelectric generator, the heat loss was 1937 W in series or 2025 W in parallel. However, the electricity yield from thermoelectric generators was still very low, namely 1.73 V, 0.132 A, or 0.23 W in a parallel arrangement, and 2.24 V, 0.134 A, or 0.3 W in a series arrangement. The low electricity produced was due to imperfect installation, the low temperature used, and thermoelectric generator performance. For the reason, further research needs to be done with better thermoelectric types.
KEYWORDS: Thermoelectric generator; heat lost; voltage; current; power

I. INTRODUCTION

The need for energy in Indonesia continues to increase along with increasing economic growth and increasing population. However, the increase in energy needs cannot be offset in terms of energy generation. Thus there needs to be innovation and research that can help supply energy. Not all communities in remote areas have access to electricity. Even they have not been touched by useful technology. The technology can help them to meet their energy needs. Meanwhile, they waste a lot of heat energy through their furnaces. The fuel combustion heat in the earthenware furnace will be partly wasted into the environment and even in considerable amounts, Mulyanto et al. [1]. Meanwhile, the heat wasted into this environment can be used to generate electricity, Pabriansyah [2], Rahman [3]. They utilize wasted heat to produce DC electricity using thermoelectric.

Research using thermoelectric generators has been widely carried out, however, the results remained unsatisfactory or the electric power produced was still low, Pebriansyah [2], Rahman [3]. Nuwayhid et al. [4] conducted a study with a thermoelectric generator module mounted on a heating furnace. The number of modules used was 15 with a maximum power obtained of 100W. Nevertheless, the price of thermoelectric modules $200 per module, so the cost spent was then very expensive. Maneewan and Chindaruksa [5] utilize heat in a biomass-fueled dryer in the drying chamber temporarily between 64^{o}C-81^{o}C. They used 12 types of thermoelectric generator modules and were able to convert 4.08% of thermal energy into electrical energy. Electricity generated was 24.4 W. Sumarjo et al. [6] also conducted a thermoelectric generator experiment, but the results obtained were still very small, namely 1.5 V without load. Pabriansyah [2] also conducted a thermoelectric generator experiment using heat from the end of the motor gas exhaust pipe. However, the result was around 3.3 V no load with 3 pieces of thermoelectric generators arranged in parallel. Nevertheless, the utilization of heat lost from earthenware furnaces was the focus of this study. This was because there were still many remote areas or villages or small islands that had not been electrified by PLN.

Utilization of heat in earthenware furnaces for DC electricity is very useful although in the meantime the electricity yield is still very small for a thermoelectric generator model. The electricity generated from this earthenware furnace can be used to charge cell phones or mobile phones, so those remote rural communities can enjoy sophisticated communication equipment.

Unfortunately, from traditional stoves, much heat is still wasted or not utilized. Therefore it is necessary to research the utilization of some of the heat waste into electrical energy. The electrical energy generated is in the form of Direct Current (DC) electrical energy. The technology used to convert heat energy into electrical energy is thermoelectric technology called thermoelectric generator (TEG), Rowe [7].

The efficiency of the furnace is a ratio between the amount of heat energy used for cooking and the energy available in the fuel, Supriyatno [8]. The concept of an efficient furnace design is to create a perfect combustion process. Complete fuel combustion can be achieved if the room temperature, fuel and fuel-air ratio are at the desired conditions.

Complete fuel combustion can be achieved if the room temperature, fuel and fuel-air ratio are at the desired conditions. Air entering through a hole with one air hole has higher efficiency, Maulana [9]. Traditional stoves have a simple form of clay that is formed in such a way, there is a hole in the front as a place to enter fuel, but this stove is inefficient because a lot of heat is wasted into the open air. As a result, this traditional stove has a low efficiency of between 5-10%, Robith [10].

II. MATERALS AND METHOD

In this study, the method used is an experimental method, which is to conduct direct testing of test equipment to obtain the desired data to answer/solve problems. The research tool scheme can be seen in Figure 1.

This scheme consists of earthenware furnaces which are designed to be non-circular flat walls, which are for easy installation of thermoelectric generators, water-filled pans, 3 thermoelectric generators (TEG) type SP1848 27145 SA, thermoelectric cooling (TEC), data loggers, thermocouples and water computer. The TEG and TEC specifications are shown in Table 1. The water in the pan is a medium for absorbing heat called energy or useful heat. In practice, the pot is to boil or cook using heat from the furnace. That is why the heat received by the pan which contains the contents is heat use. TEG specification is given in table 1.

Before the fuel was put into the furnace, the fuel (shell charcoal) was weighed first. To burn the charcoal easily, kerosene was needed. Kerosene added to charcoal had also been weighed as well. The water put in the pan was weighed too so that the heat absorbed by the water could be predicted.

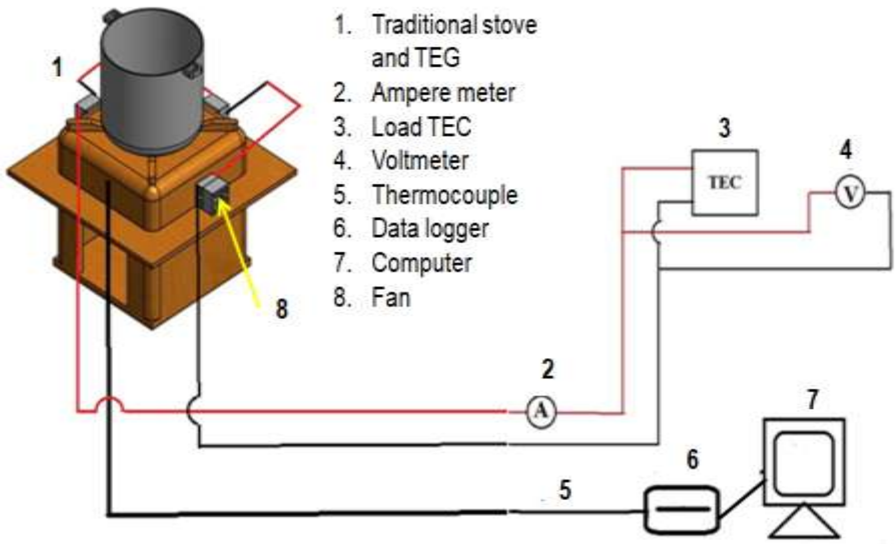

Figure 1. Schematic diagram of the experimental apparatus

Tabel 1. Spesification of TEG and TEC

TEG	
Material	Ceramic / Bismuth Telluride
Colour	White
Parametric model	SP1848-27145 SA
Temperature(°C)	150
Open-circuit voltage (V):	4.8V
Current (mA):	20-225°C: 0.97; 40-368°C: 1.8; 60-469°C: 2.4; 80-559°C: 3.6°C; 100-669°C: 4.8
Module weight	25g / 0.89oz
Module size	4 x 4 x 0.4 cm atau 1.6 x 1.6 x 0.2 in
TEC	
Material	Metal
Voltage	12V
Electrical current	5.8 A
Power, $Q_{c, max}$	50-60 W
Weight	350g
Module size	4 x 4 x 0.4 cm

After the fire is burning, the temperature is measured every 15 minutes, the electric power output and fan electric power are also measured every 15 minutes. Power is measured using a digital ampere and voltmeter while the temperature is measured using a K type thermocouple that has been calibrated with an accuracy of ± 0.5 ° C. The scales used are digital scales with a 0.01 g resolution. The mass of fuel (coconut shell) used is 0.65-0.68 kg, and the mass of kerosene is around 0.03 g, and the mass of water put in the pan is 5.1-5.2 kg.

Research results are presented in the form of graphs or tables to facilitate the analysis process. The temperatures recorded in the experiment were TEG hot side temperature, TEG cold temperature, water temperature, and ambient temperature. For research without thermoelectric generators, the temperature recorded was water and ambient temperatures. Figure 2 shows the recording temperature without a thermoelectric generator.

The useful energy can be predicted using equation (1), which was taken from Holman [11], and it was also used by Mirmanto et al. [12]. It is written as:

$$Qu = mc_p dT / dt \qquad (1)$$

Qu is the usefull heat (W), m is the water mass (kg), dT/dt is the temperature change over the time change (°C/s). The combustion energy given to the traditional stove can be expressed as:

$$Qbb = m_{bb} h_{LV} / t \qquad (2)$$

Equation (2) was also used by Mirmanto et al. [12]. Qbb is the heat released from the combustion (W), m_{bb} is the fuel mass (kg), h_{LV} represents the low value of heating (J/kg). Then the heat loss can be determined using equation (3).

$$Qloss = Qbb - Qu \qquad (3)$$

Qloss is the heat coming out from the stove to the ambient (W). The experimental useful energy that can be obtained using equation (1) but dt must be scratched out, then it becomes:

$$Euse = mc_p dT \qquad (4)$$

Euse is the useful energy absorbed by the water (J). To know the efficiency, the energy given to the stove must be predicted. The energy can be estimated using equation (5).

$$Ebb = m_{bb} LHV \qquad (5)$$

$$\eta = \frac{Euse}{Ebb} \qquad (6)$$

III. RESULTS AND DISCUSSION

Results in this study are given in the form of graphs and tables to make easy explanations. First of all, the recording temperatures are presented in Figure 2 containing water and ambient temperatures. The temperature can be used for predicting the useful energy and heat loss. The water temperature determines the useful energy while the ambient temperature influences the heat loss.

Figure 2 indicates that the water temperature increases and then it is constant after a while, while the ambient temperature is just almost constant all the time. The increased water

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temperature was due to the heat coming from the combustion of fuel.

All useful energy lines presented in figure 3 increase with increasing the observation time. This was due to the temperature difference. The temperature difference increases with time until it reaches approximately 70°C. The phenomenon occurs for all cases in this study. However, the useful energy is almost the same for all cases. This was also found by several researchers, but what is the useful thing from this study? It is the efficiency of the stove.

Ebb is the energy released from the combustion of fuel (J), m_{bb} is the mass of the fuel (kg), and LHV is the low heating value (J/kg). Then Ebb can be seen in figure 4. Figure 4 indicates that the energy given to the stove is the same for the three cases, as its difference value is small. The efficiency can be predicted using equation (6).

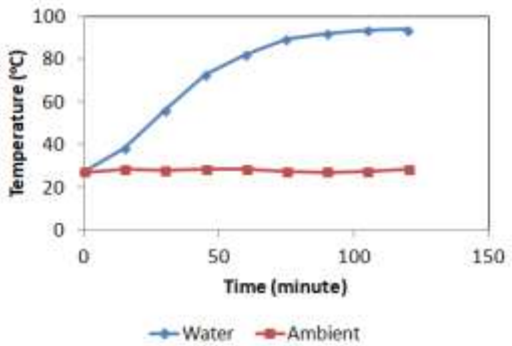

Figure 2. Relationship of water and ambient temperatures and observation time for experiments without TEG.

Figure 5 indicates that adding TEG increases efficiency. The efficiency difference is significant, it is of approximately 0.031 or 11% of efficiency without TEG. Nevertheless, the stove efficiency is still low because it is less than 50%. Therefore, there is an opportunity to perform further research to increase traditional stove efficiency. However, it should be noted that the circuit TEG arrangement does not affect efficiency. This is shown in figure 5, experiments with series and parallel TEG arrangements result in similar efficiency values.

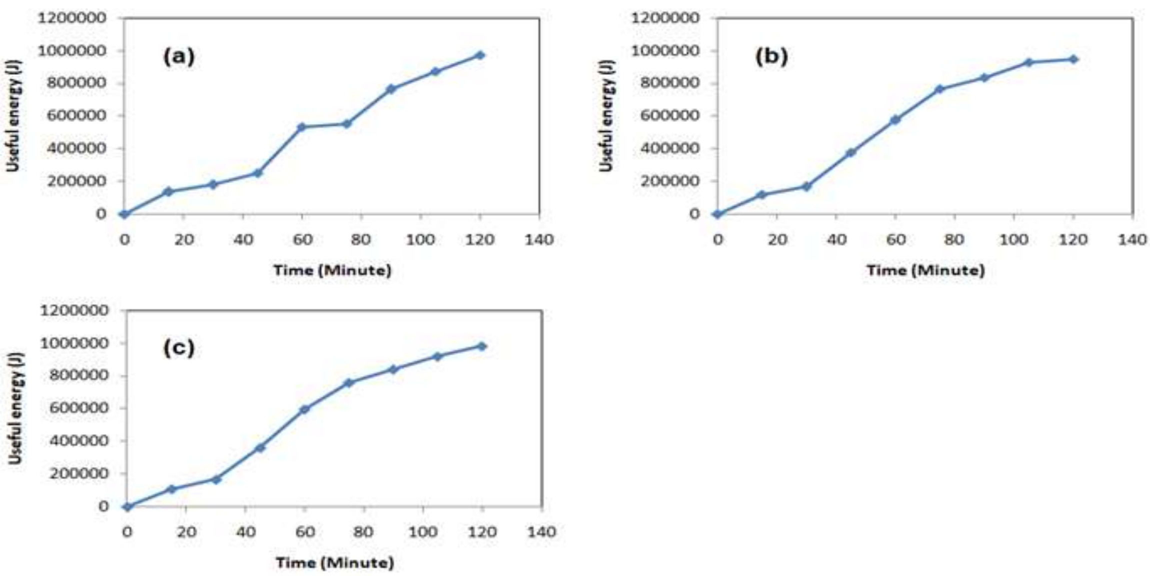

Figure 3. Relationship of useful energy and time observation; (a) without TEG, (b) with a series TEG arrangement, (c) with a parallel TEG arrangement.

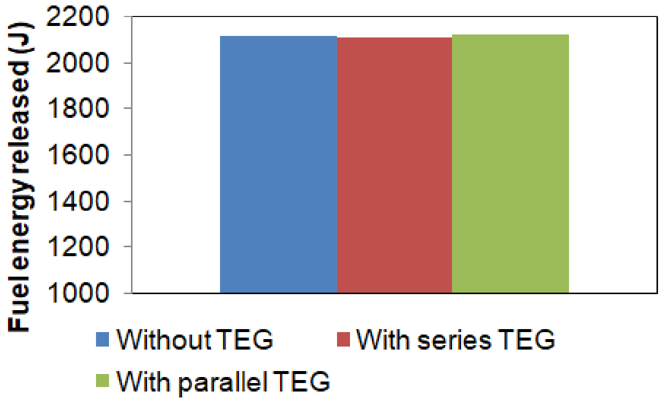

Figure 4. Energy released in the stove for the three cases

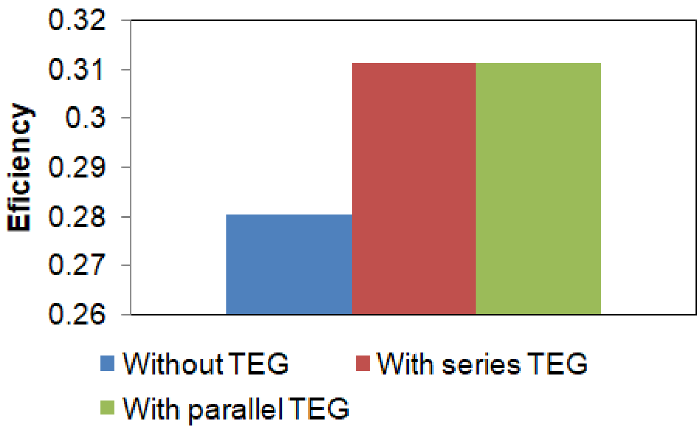

Figure 5. Efficiency of the stove for the three different cases

IV. CONCLUSION

The experiment to know the effect of TEG arrangement on the stove efficiency had been performed and the remarkable results are: (i) Using TEG increase significantly the traditional stove efficiency. (ii) The TEG arrangements do not affect stove efficiency. (iii) The stove efficiency is still very low and it needs to be improved.

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