

Araştırma Makalesi

A Thermovoltaic Voltage Source Integrated with a Samovar

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Abstract: Renewable energy sources are becoming very important in today's World. Waste heat from industrial processes is very common in the world and such sources can be used to obtain electric power. Thermovoltaic power sources are getting cheaper and their electrical power output is getting higher due to technological developments. They have been used with waste heat sources such as hot water flowing out of factories and to obtain electrical sources. Nowadays, new application areas of thermovoltaic power sources are being looked for. Samovars, which burn brushwood, are pretty commonly used in rural areas to prepare warm drinks such as tea. Samovars only supply thermal power to boil water and they can be regarded as low-grade heat sources since they release a considerable amount of heat to the ambience. Integrating a thermovoltaic power source onto a samovar would turn it into a voltage source and also increase its overall energy efficiency. Such a system may allow charging batteries of low power loads such as flashlights and cell phones in rural areas where it is hard to reach the electrical grid. In this study, a thermovoltaic power source is integrated with a samovar for the first time in the literature and the performance of such a system is experimentally inspected. It has been found that the system's electrical power output is low, the air convection around the semiconductor pairs of the module may be contributing to its low power performance, and a more complex system model is needed to model it accurately.

Keywords: Samovar, Thermovoltaic Voltage Source, Renewable Energy

Semaver ile Entegre Termovoltaik Gerilim Kaynağı

Öz. Yenilenebilir enerji kaynakları günümüz dünyasında çok önemli hale gelmektedir. Endüstriyel proseslerden kaynaklanan atık ısı dünyada çok yaygındır ve bu tür kaynaklar elektrik enerjisi elde etmek için kullanılabilir. Teknolojik gelişmelere bağlı olarak termovoltaik güç kaynakları ucuzlamakta ve sağladıkları elektrik güç artmaktadır. Günümüzde termovoltaik güç kaynakları için yeni uygulama sahaları aranmaktadır. Çalı çırpı yakan semaverler, kırsal kesimlerde çay gibi sıcak içecekler hazırlamak için oldukça yaygın olarak kullanılmaktadır. Semaverler yalnızca termal güç sağlar. Semaverler sadece suyu kaynatmak için termal güç sağlarlar ve ortama önemli miktarda ısı saldıkları için düşük kaliteli ısı kaynakları olarak kabul edilebilirler. Bir termovoltaik güç kaynağının bir semavere entegre edilmesi, onu bir gerilim kaynağına dönüştürür ve aynı zamanda genel enerji verimliliğini de artırır. Böyle bir sistem, elektrik şebekesine ulaşmanın zor olduğu kırsal alanlarda el feneri ve cep telefonu gibi düşük güçlü yüklerle sahip pillerin şarj edilmesini sağlayabilir. Bu çalışmada literatürde ilk kez termovoltaik bir güç kaynağı semaver ile entegre edilmiş ve böyle bir sistemin performansı deneysel olarak incelenmiştir. Sistemin elektrik güç çıkışının düşük olduğu, modülün yarı iletken çiftleri etrafındaki hava

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konveksiyonunun düşük güç performansına katkıda bulunduğu ve sistemi doğru bir şekilde modellemek için daha karmaşık bir modele ihtiyaç duyulduğu bulunmuştur.

Anahtar kelimeler: *Semaver, Termovoltajik Gerilim Kaynağı, Yenilenebilir Enerji.*

1. Introduction

In the modern world, fossil fuels are used as the main and most common source to meet energy needs in every field [1]. Due to the negative environmental effects, high costs, and limited resources of fossil fuels, it has become necessary to search for more environmentally friendly, inexpensive, and easily obtainable energy sources [2]. Apart from the energy used in energy usage areas, waste heat is released to the environment as a loss [3]. Low-grade heat accounts for more than half of the total dissipated heat sources in industries [4]. Efficient recovery of low-grade heat into useful electricity not only decreases the consumption of fossil fuels but also reduces its impact on the environment [4]. More information on thermoelectric devices and their application can be found in [5]. Reviews on thermoelectric and thermophotovoltaic power generation systems are given in [6-8]. Thermovoltaic cells are devices that can be used as renewable voltage sources [4, 5]. They require a temperature difference for their operation [5]. The semiconductor ones are more efficient than others [5, 9]. There are thermovoltaic systems that use waste heat to obtain electrical power [4, 5, 10-11]. For example, truck exhausts are also equipped with thermovoltaic cells to obtain extra electrical power for a truck power system [12]. They require a maximum power tracking system [13]. New application areas for thermovoltaic cells are sought [5-8]. Tea is the most consumed drink in the Republic of Türkiye [14]. The samovars are commonly used tea-preparing devices in the middle-east region [15]. Their design has been modernized in recent decades [16]. Samovars are used in rural areas to prepare tea by burning brushwood such as dry tree branches, straws, etc. in Türkiye. To the best of our knowledge, a samovar has not been integrated with a thermovoltaic generator yet. Such a heat source can also be designed to have a thermal voltage source and can be used to charge small devices such as flashlights and cell phones. The aim of the study is to integrate a samovar with a thermovoltaic generator and examine its performance experimentally. Such a system can provide electric power even during nighttime since it uses brushwood for heating, not sunlight as a photovoltaic module does. A Peltier module is used as the thermovoltaic generator. It is mounted on the samovar. A cooling fin is used to cool down the cold plate of the module further. A metal mounting part between the samovar and its hot plate is used to prevent it from overheating. The experiments are done to measure its electrical variables and plate temperatures. Its performance is evaluated.

The study is structured as follows. The thermovoltaic module is introduced in the second section. The samovar and its integration with the module are explained in the third section. The experimental results are given in the fourth section. The study is concluded in the last section.

2. Thermovoltaic Module

TEC1-12706 thermoelectric cooler module operates

with the Peltier effect and is used to make coolers [17]. Its solder construction can only stand temperatures up to 138 °C. A TEC1-12706 is integrated into a samovar used as a thermal thermoelectric generator in this study. Its photograph is shown in Figure 1.a. Its equivalent circuit, which was given in [18], is shown in Figure 1.b. The output voltage of the thermoelectric generator module can be given as

$$V_{TEG} = V_{OC} - R_{TEG}I_{TEG} \quad (1)$$

where I_{TEG} is the module current, V_{TEG} is the output voltage of the module, V_{OC} is the open circuit voltage of the module, and R_{TEG} is the equivalent series resistance of the module.

The electric power output of such a module depends on the surface temperature difference of the module's ceramic plates.

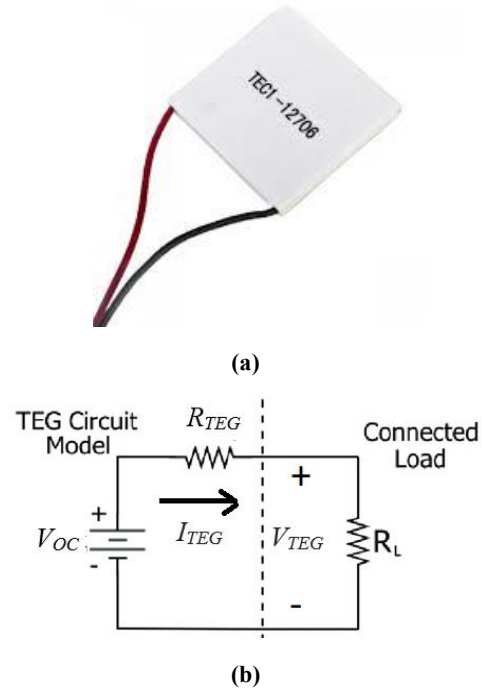


Fig. 1. a) The TEG module used and b) its equivalent electrical circuit

3. The Samovar with a TEG Module

A photograph of the samovar model used in this study is shown in Figure 2. The power module has a planer geometry and it cannot touch the samovar completely since the samovar has a cylindrical structure. A picture taken by a thermal camera has shown that the body temperature of the samovar is found to be higher than its maximum allowable temperature, 138 °C as shown in Figure 3. That's why a metal mounting part is used to connect its hot side plate on the samovar to obtain a temperature as shown in Figures 2 and 4. Such a part would decrease the thermal efficiency due to the air regions within the connector. A finned cooler can be added to increase the thermal efficiency of the system as done in a renewable energy

system [19]. An aluminum radiator is also connected to the cold side plate of the TEG module to cool it down as shown in Figures 2, 4, and 5. Such a radiator would help to increase the temperature difference between the hot and cold plates. A thermal adhesive is applied to the TEG module in the mounting process as shown in Figure 6.



Fig. 2. The samovar model integrated with the TEG module.



Fig. 3. The thermal camera view of the samovar system.

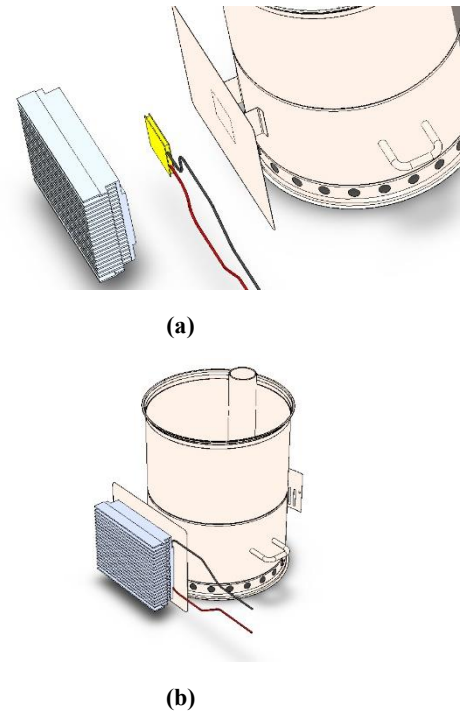


Fig. 4. a) The TEG module, the aluminum heat radiator, and the samovar, and b) The integration of the TEG module with the samovar and the aluminum heat radiator.



Fig. 5. The aluminum heat radiator used.



Fig. 6. The gluing of the TEG module with the thermal adhesive used.

4. Experimental Results and Discussion

The experimental results are given in this section. The electrical circuit is given in Figure 7 used to measure the electric power output of the system when the samovar is heated with brushwood. The devices which are used in the experiments are given in Table 1.

Table 1. The electrical devices used in the experiments.

Device	Brand/Specifications
Voltmeter	Proskit MT-1210
Amperemeter	Extech EX410A
Potentiometer	Multimeter
	560 Ohm, 0.52 A (LH)
Thermoelectric Module	TEC1-12706

The circuit utilizes an adjustable resistor (a potentiometer) to change the load current. An amperemeter is used to measure the TEG current, I_{TEG} , and a voltmeter is used to measure the TEG voltage, V_{TEG} . A photograph of the electrical measurement system is given in Figure 8. The output power of the module is given as

$$P_{out} = V_{TEG} \cdot I_{TEG} \tag{2}$$

The electrical power is a function of the difference between the cold and hot plate temperatures. The temperature difference between the plates of the module is given as

$$\Delta T = T_{hot} - T_{cold} \tag{3}$$

where T_{cold} and T_{hot} are the cold and hot plate temperatures.

The ambient temperature, $T_{ambient}$, was also measured during the experiments.

The samovar was lit as shown in Figure 2 and was waited for it to heat up. The experiments are performed for the various operation points. The voltage and current of the TEG module are measured and the output power of the module is calculated with Eq. (2). The electrical measurements and the calculated output power are shown in Figures 9-11.

Using Eq. (3), the following temperature differences were calculated: $\Delta T=50.6$ °C, $\Delta T=64.9$ °C, and $\Delta T=68.5$ °C for Figures 9-11 respectively.

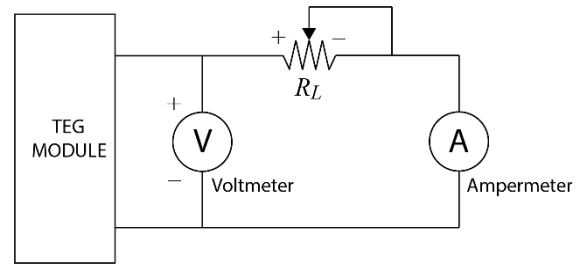


Fig. 7. The electrical circuit used for the electrical measurements.

The electrical power was expected to increase when the temperature difference ΔT increased. However, the experimental results show that the maximum output power is obtained for $\Delta T=50.6$ °C as shown in Figure 9. An explanation is sought for this. The series resistance of the module is calculated using curve-fitting to the data given in Figures 9-11. $R_{TEG}=14.0378$ Ohm, $R_{TEG}=12.1243$ Ohm, and $R_{TEG}=12.1243$ Ohm have been calculated for the operation characteristics shown in Figures 9-11 respectively. The higher resistance may mean that the module’s semiconductor pairs are cooler. The reason might be that the experiment is done outside and the air may be flowing through the power model and around the power module’s semiconductor pairs that result in the semiconductor pairs being cooled, their output power cannot be only dependent on the temperature difference of the module plates in this case, and the wind speed or the convection should be taken into account. A TEG system model, which combines the thermal and the electrical systems of the module, is given in [9] and it is shown in Figure 12. Such a model can be modified to take the convection into the account to model the TEG system used here. It has been also found that the value of the output power is low and its maximum value is found to be 16 mW. The number of the TEG modules must be increased for more output power.



Fig. 8. The electrical measurement system.

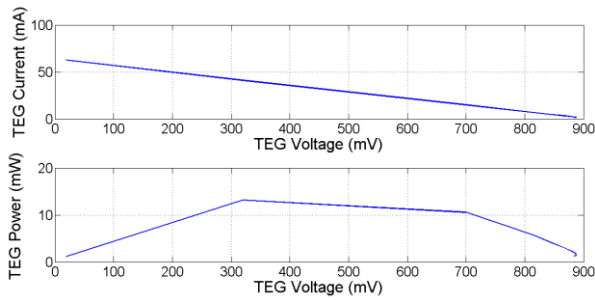


Fig. 9. The experimentally obtained a) voltage-current characteristic and b) the voltage-output power of the TEG module when $T_{hot}=92^{\circ}\text{C}$, $T_{cold}=41.4^{\circ}\text{C}$, $T_{ambient}=19.4^{\circ}\text{C}$, $\Delta T = 50.6^{\circ}\text{C}$.

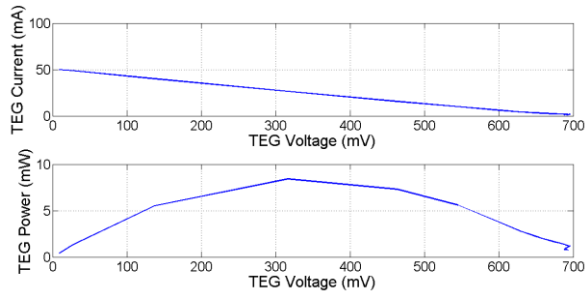


Fig. 10. a) The voltage-current characteristic and b) the voltage-output power of the TEG module when $T_{hot}=99.7^{\circ}\text{C}$, $T_{cold}=34.8^{\circ}\text{C}$, $T_{ambient}=19.4^{\circ}\text{C}$, $\Delta T = 64.9^{\circ}\text{C}$.

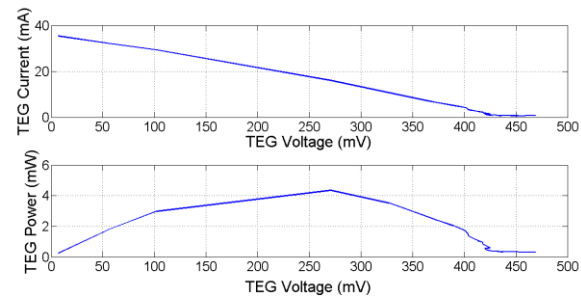


Fig. 11. a) The voltage-current characteristic and b) the voltage-output power of the TEG module when $T_{hot}=97.6^{\circ}\text{C}$, $T_{cold}=29.1^{\circ}\text{C}$, $T_{ambient}=19.2^{\circ}\text{C}$, $\Delta T = 68.5^{\circ}\text{C}$.

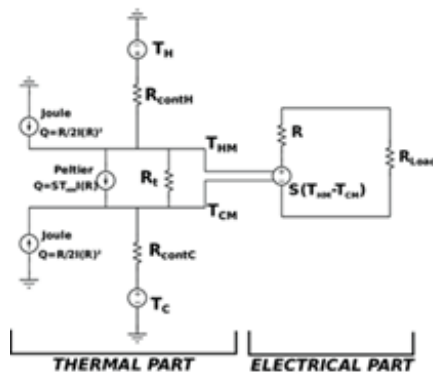


Fig. 12. A more complex TEG system model given in [9].

5. Conclusion

In this study, a samovar was combined with a TEG module. The proof is the concept has been shown experimentally. As long as brushwood is sustainable in a region, such a system would also stay sustainable. The current-voltage characteristic and the output power of the system were obtained. When the temperature difference of the plates is 50.6°C , the electrical power obtained is found to be around 16 mW which is pretty low. More modules are needed to charge a load such as a cellular phone in an acceptable duration. However, such a simple system may provide a simple charging solution for cell phones in rural areas, and, perhaps, using tellurium-based thermoelectric modules can increase electrical power output from such a system due to their higher figure of merit (zT) value, can lower the cost due to higher power output, and increase the system’s efficiency. Also, the module can be mounted closer to the samovar to increase its hot plate temperature and, therefore, its output power without reaching 138°C . Such a system can provide electric power even during nighttime since it uses brushwood for heating. Such a system can increase its efficiency during the night since the ambient temperature falls down considerably in most of the regions of Türkiye during the night. A better thermal model is needed to model the performance of the system which takes the convection into account. As a future work, we suggest that rice straw burners given in [18] can also be combined with TEGs to produce electrical power, and the optimization and the enthalpy analysis of such a system can also be made as done in [19].

Author Contribution

Data curation – Reşat Mutlu (RM); Formal analysis –RM; Investigation – RM, Erdal Kılıç (EK), Ertuğrul Karakulak (EKA); Experimental Performance –EKA, EK; Data Collection EKA, EK; Processing – RM, EKA, EK; Literature review – RM, EKA, EK; Writing – RM; Review and editing – RM, EKA, EK;

Declaration of Competing Interest

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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