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Thermoelectric Generator using Ice-Water Mixture as Heat Sink and Ambient Air as Heat Source

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Abstract: Thermoelectric generator can utilize various combinations of heat sink and heat source. In this paper, the performance of thermoelectric generator that uses surrounding air as heat source and coldness from ice-water mixture is presented. The objective was to evaluate the open circuit voltage produced by thermoelectric generator, at a range of differences in temperature between the cold and hot surfaces of module. In this work, the thermoelectric module was placed between aluminum heat sink and cold beverage container that contained ice-water mixture. The heat sink operates using the difference in buoyancy of surrounding air (i.e. natural convection). The hot and cold surfaces temperature of thermoelectric modules was measured using Type-K thermocouples. A digital multimeter was connected to the thermoelectric module for measurement of open circuit voltage. The open circuit voltage produced by the thermoelectric generator was linearly proportional to the magnitude of difference in temperature of two surfaces of a thermoelectric module. The electrical power produced by the generator was up to 14 miliWatt. A simple test showed that with a suitable voltage amplification device, this thermoelectric generator can supply enough power for LED bulbs. The finding presented is suitable for the development of energy scavenging devices, which is relevant to stand-alone power generation system.

Keywords: Condensation, cold waste, energy scavenging, relative humidity, thermoelectric generator.

I. INTRODUCTION

Thermoelectric generators usually use heat source with temperature that is higher than its ambient temperature. For instance, heat waste from combustion in engines can be recovered and use as the heat source to generate electricity using thermoelectric generator. Since the heat source temperature is higher than the temperature of surrounding air, the air could serve as the heat sink. However, it is not common to use surrounding air as the heat source and bodies with lower temperature than surrounding air as the heat sink. In this paper, the feasibility study on the use of thermoelectric generator using cold beverage container with ice-water mixture as heat sink and surrounding air as heat source is presented.

Thermoelectric module is an elegant device that has various capabilities. Other than acting as heat pump, with a suitable control strategy, thermoelectric module could act as temperature controller and measure instantaneous heat flow [1]. The Coefficient of Performance of thermoelectric module in heat pump application can be improve significantly by combining heating and cooling [2], or with addition of intermediate water tank [3]. For the application in power generation, various combinations of heat sink and heat source were reported [4].

Heat source for thermoelectric generator can be taken from various sources such as automobile exhaust [5], stove [6] and rocks [7]. However, the combination of heat source and cooling system need to be given an attention. For instance, advanced cooling system for thermoelectric generator has been reported in [8].

The use of cold waste from cryogenic plant poses lower thermoelectric power generator performance due to accumulation of ice that make heat transfer significantly reduced [9]. Earlier attempt to utilize waste cold from LNG was done through analytical and numerical methods [10]. To date, there is no attempt reported in literature on the utilization of cold waste from ice-water mixture.

In this paper, the performance of thermoelectric generator that used ambient air as heat source and cold beverage container with ice-water mixture is presented. The variations of electrical power output with respect to the temperature difference between thermoelectric surfaces are reported.

II. EXPERIMENT TO EVALUATE PERFORMANCE OF THERMOELECTRIC GENERATOR

A. Apparatus

The thermoelectric module used was TEM-22W-7V56S with the dimension of 56 mm x 56 mm x 4 mm. This module can produce 22 Watt provided the temperature different between two surfaces of the module are sufficiently large. The module can operate up to 430°C; however no limit on the lowest operational temperature was stated.

The dimension of the heat sink was 80 mm x 80 mm x 40 mm with 14 prismatic fins. The spacing between fins is not even, as in Fig. 1.

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The heat sink was made from aluminum. There was no fan attached to the heat sink.

The cold beverage container was made from plastic with the dimension of 300 mm x 100 mm x 300 mm. It has flat surfaces so that thermoelectric can be attached to the container without require any adaptor (Fig. 2). The container is like the type that is commonly available market.

Two Type-K thermocouples that are connected to digital thermocouple meter were used to measure the temperature of heat sink and surface of cold beverage container. The thermoelectric generator was connected to a multimeter, so that the open circuit voltage can be measured.

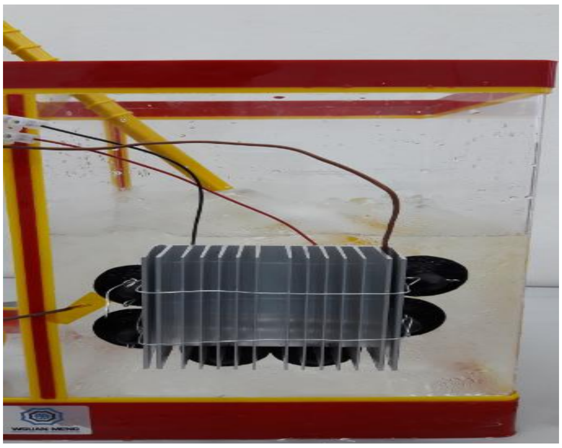

Fig. 1 The heat sink is attached to the cold beverage drink with rubber suction cups

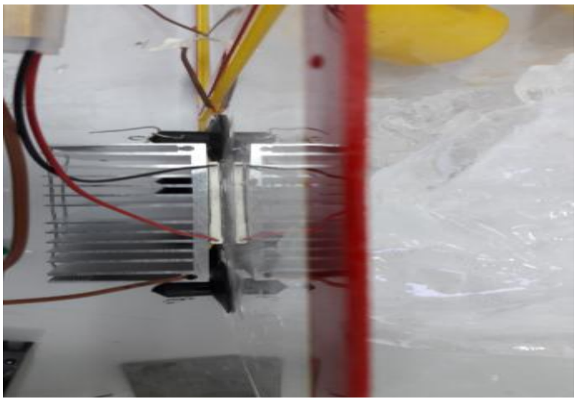

Fig. 2 Different view of Fig. 1 to show the position of thermoelectric generator (between heat sink and cold beverage container)

B. Experimental procedure

The mixture of ice and water was placed inside the cold beverage container. Then, the readings on the digital thermocouple meter and the multimeter were recorded. Throughout the experiment, the surrounding air temperature was between 32°C and 33°C.

III. RESULTS

Fig. 3 shows the variation of heat source and heat sink throughout the experiment. The range of heat source temperature was between 31°C and 25°C. Since this experiment was conducted in Malaysia, where the relative humidity of 70% is common, condensation may significantly increase the rate of heat transfer from surrounding air to the heat sink. This is beneficial to the performance of thermoelectric generator. For the heat sink temperature, the lowest temperature was 6 °C. This was higher than the temperature of ice-water mixture, which is generally accepted at 0°C. The condensation of water vapor on the surface of cold beverage container and temperature increase within the wall may explain the increase from 0°C to 6°C.

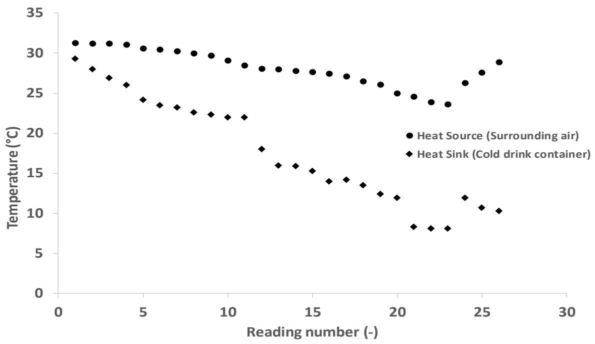

Fig. 3 The temperatures of surrounding air and the container

For the open circuit voltage, the magnitude of the voltage produced by the thermoelectric module is almost linearly proportional to the temperature difference between its surfaces (Fig. 4). However, the linear fitting to the data shows that the voltage does not intercept at the origin of the graph. This may happen due to some error in the measurement of surface temperature of thermoelectric modules, where Type-K thermocouples can have uncertainties up to 0.5 °C.

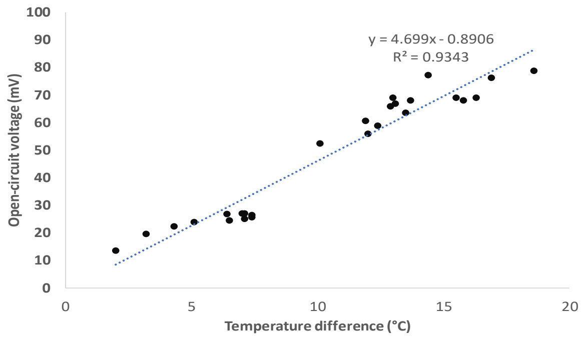

Fig. 4 The data of open circuit voltage at specific temperature difference compared to the straight line fitting

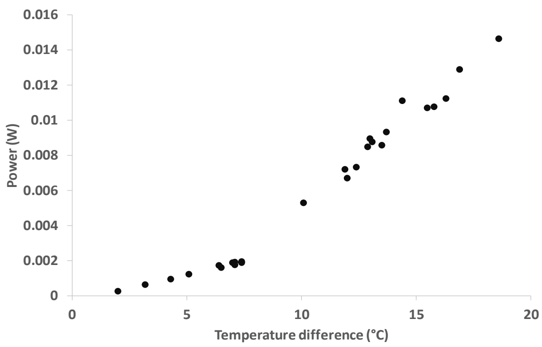

Fig. 5 Electrical power produce by thermoelectric generator at various temperature difference

Fig. 5 shows the inferred electrical power produced by the thermoelectric generator. The increase in electrical power was not linearly proportional to temperature difference, where the rate of increase in power per unit temperature difference is more significant at higher temperature difference.

IV. DISCUSSION

As part of additional testing, the electricity generated by thermoelectric module was used to power LED bulbs (Fig.6). It is proven that the electricity is enough to light up the bulb, provided a suitable voltage amplifier was used. LED bulbs may suitable for decoration of cold beverage container. Further tests to evaluate the suitability of using the electricity generated by thermoelectric module in other applications are required.

Since condensation may happens on the surface of heat sink, it is worth to conduct further investigation on method to utilize the phenomenon to improve the performance of heat transfer between surrounding air and the heat sink. For instance, a heat sink with a very efficient surface for condensation may lead to a better performance of thermoelectric generator since condensate can flow freely from the surface. This provides a direct contact between surface and air, with no additional thermal resistance from condensate.

Fig. 6 Electric power generated by thermoelectric was sufficent for usage by two LED bulbs

V. CONCLUSION

The open circuit voltage of thermoelectric generator using the combination of surrounding air and cold beverage container with ice-water mixture were evaluated. Although the electrical power produced by thermoelectric generator was too small for the usage of most electrical devices, it was proven its ability to light up LED bulbs by assistance of suitable voltage amplifier. Another advantage of this thermoelectric generator system is it does not consume any electricity for its operation, so the electrical power produced by the generator is equal to its net power output. The findings presented in this paper are beneficial to street hawkers, where they could produce electricity from the sources that are available within their surroundings. Future work is on the evaluation of effect of condensation on the surface of heat sink to the performance of thermoelectric generator.

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