



# EXPERIMENTAL INVESTIGATION OF A LIQUID COOLING SYSTEM FOR A THERMOELECTRIC POWER GENERATOR SYSTEM USING ETHYLENE GLYCOL AS A NEW COOLANT

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## ABSTRACT

In the present experimental investigation, ethylene glycol cooling in a plate-fin heat sink was attached inside an aluminum cooling block for the cooling unit of a thermoelectric (TE) power generator system. The plate-fin heat sink with two different fin heights was made from aluminum with length, width and base thickness of 300, 200, and 25 mm, respectively. The ethylene glycol was used as a coolant. The effects of fin height, coolant volume flow rate, and hot side surface temperature were considered for the temperature differences between the hot side surface and cold side surface of the TE power module. The ethylene glycol cooling of the rectangular plate-fin heat sink inside the aluminum cooling block was compared to water and air cooling. The plate-fin heat sink for ethylene glycol cooling showed a significant effect on the cold side surface of the TE power module for cooling of the TE power generator system. The experiments were performed under conditions of the heat input to the hot side surface area within 60 min after steady state, for which the volumetric flow rates were 0.005, 0.010 and 0.015 m<sup>3</sup>/min. The results indicated heat transfer rate increase with increasing coolant volume flow rate and higher fin. When compared to the water and air cooling methods, the plate-fin is attached inside the aluminum cooling block gives the highest efficiency. The results of this study could be used for guidance that will enable the design of a cooling system with improved heat transfer performance in a TE power generator system.

**Keywords:** *Thermoelectric power generators; A liquid cooling system; Ethylene glycol coolant; Plate-fin heat sink*

## 1. INTRODUCTION

Due to increasing demand for higher performance from TE generators under temperature control on the cold side surface of the TE power module and level reliability of heat rejection, improvements will have required for these devices. The development of a new cooling technology for physical performance has rapidly increased, especially in electronic engineering and other related fields. Over the past several years, various articles and reports have been presented evaluating the performance of TE power generators. Rowe and Min (1996) found an increase in the conversion efficiency of a TE module by employing a lower heat transfer rate through the module. Zhao and Lu (2002) presented an analytical and numerical study on the heat transfer characteristics of forced convection across a microchannel heat sink. Cheng and Lin (2005) proposed a method for using a genetic algorithm to maximize cooling capacity and found that optimizing the dimensions of the TE cooling module could increase its cooling capacity. Yang et al. (2005) studied the transient response of TE coolers with and without mass loads through examination of both the minimum temperature reached and the time constants involved in the cooling and the recovering stages. In the same year, Peles et al. (2005) investigated heat transfer and pressure drop phenomena over a bank of micro pin fins. It was found that those very low thermal resistances are achievable using a pin fin heat sink. The thermal resistance values are comparable with the data obtained in microchannel convective flows. Siu-Ho et al. (2006) measured pressure drop and temperature distribution of a single-phase micro-pin-fin heat sink for evaluating average friction factor and

local averaged heat transfer coefficient/Nusselt number. Kim et al. (2008) compared the thermal performances of the two types of heat sinks most commonly used in the electronic equipment cooling: plate-fin and pin-fin heat sinks. The results showed that plate-fin heat sinks possess lower thermal resistances than optimized pin-fin heat sinks when dimensionless pumping power is small and the dimensionless length of heat sinks is large. On the contrary, the optimized pin-fin heat sinks have smaller thermal resistances when dimensionless pumping power is large and the dimensionless length of heat sinks is small.

Whelan and Robinson (2009) investigated the cooling capabilities of impinging water jet arrays. It was found that the confined-submerged tests yield greater heat transfer coefficients compared with their free jet counterparts. Hsiao et al. (2010) developed of thermoelectric generators and a cooling system for improving the efficiency of an IC engine. Two potential positions on an automobile chosen to apply this module e.g. exhaust pipe and radiator to check the feasibility. The results showed that the better efficiency of the thermoelectric module on the exhaust than on the radiator. Champier et al. (2011) presented a prototype thermoelectric generator for a fire stove. It found that the performing of the generator mostly depends on the heat transfer through the modules and especially on the thermal contact resistance. Pang et al. (2012) investigated the cooling system of an internal combustion engine by coupling one-dimensional and three-dimensional simulations. The results of the study showed that the thermal performance of the radiator played a critical role in cooling system performance. Wang et al. (2012) developed three-dimensional numerical model of TEs. It was found that the properties and the heat losses have significant effects on the TEC performance. After that, Mehrtash et al. (2013) studied the effect of

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inclination on a plate-fin heat sink on heat dissipation by numerical simulation with three-dimensional steady-state natural convection. Rubio-Jimenez et al. (2013) compared of the performances of online and offset micro pin-fin heat sinks with variable fin densities. The results indicated that the offset micro pin-fin heat sink is a good alternative for cooling the IC chips of 2016. Jang et al. (2013) investigated the effects of flue gas temperature and flue gas speed on a 3-D numerical model of a TEG module with plate-fin used in a waste heat recovery system. In the same year, Fan et al. (2013) studied a cylindrical oblique fin minichannel heat sink to fit over cylindrical heat sources in the form of an enveloping jacket. It was found that the averaged Nusselt number,  $Nu_{ave}$  for the cylindrical oblique-cut fin minichannel heat sink increases up to 75.6% and the total thermal resistance decreases up to 59.1% when compared with the conventional straight fin minichannel heat sink. Favrel et al. (2014) investigated the electric power extractable from a system equipped with thermoelectric modules and limits on electricity generation the influence. It was found that each thermoelectric fabrication there is an ideal occupancy rate which can vary greatly. Prajapati et al. (2015) investigated channel configurations are uniform cross-section, diverging cross-section and segmented finned microchannels. It was found that performs of diverging cross-section channels is better than the uniform cross-section channels.

In this paper, the main objective is to study the heat transfer characteristics of an aluminum cooling plate-fin heat sink block for TE power generator systems. The effects of relevant parameters for ethylene glycol cooling on the cold side of the TE power module were considered.

## 2. EXPERIMENTAL SETUP

The experimental setup for generation of the performance test for the TE power modules is shown in Fig. 1. The test device consists of an electric heater, a TE power module, an ethylene glycol cooling system and a data acquisition system. The closed loop ethylene glycol cooling system consists of a storage tank, fluid pump, flow meter, and radiator. The test section and connections of the ethylene glycol cooling system were designed such that the parts could be assembled easily or repaired easily. The researchers selected TE power modules of TEG1-127-40-40-250 for the experiment because they are commercially available TE modules at low cost, as shown in Table 1 below. The TE power modules were clamped between the aluminum cooling block and the electric heater (2,700 W at 20 cm x 40 cm). The electric heater was made of stainless steel. The resistance ribbons were wound on a mica sheet to provide the heat source, which was proportional to the applied voltage. The electric heating comprised a plate-type heat exchanger with ethylene glycol coolant flowing through the interior multi fin of the aluminum cooling block to control the cold-end temperature of the TE power module. The ethylene glycol coolant flows through these multi fin, absorbing excess heat from the cold side surface of the TE power module, after which it exits the aluminum cooling block on its way to the radiator. At the radiator, the ethylene glycol coolant is pushed through a network of even narrower channels, which are cooled by having air blown over them by a fan. After that, the ethylene glycol coolant then flows back to the reservoir and begins its journey again. The volumetric flow rate of the ethylene glycol coolant is controlled by adjusting the valve and measuring with a flow meter. The test sections fabricated from the aluminum cooling block with the details are listed in Table 2. The temperatures measured for ethylene glycol cooling at various positions are shown in Fig. 1.

The plate-fin heat sink is presented in Fig. 2. This experiment was conducted with various ethylene glycol coolant flow rates, fin heights for the plate-fin heat sink, and temperatures on the hot side surface of the TE power module. The hot side surface temperature of the TE power module was adjusted to achieve the desired result by setting the run condition of the electric heater.

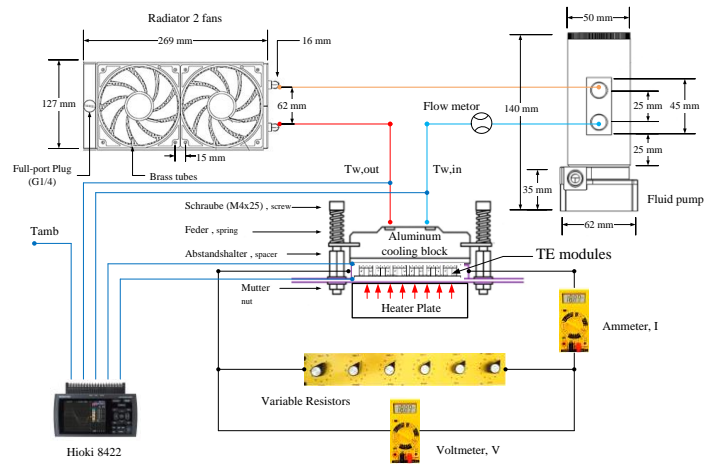
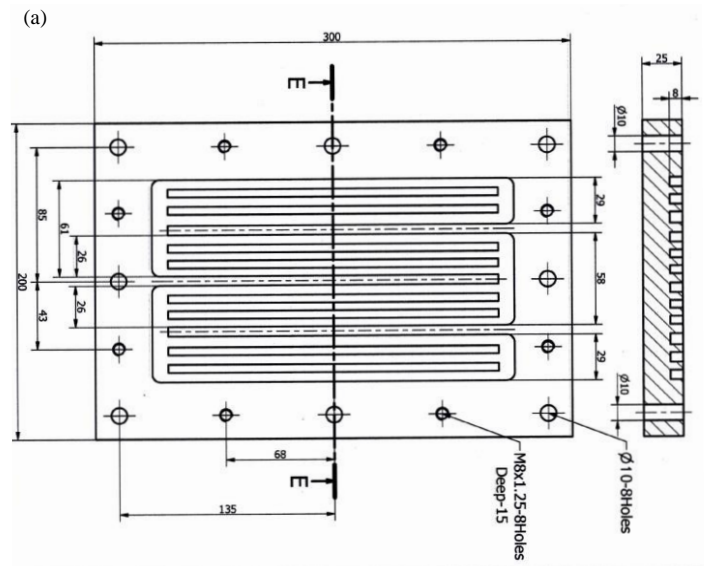


Fig. 1 Schematic diagram of the experimental apparatus



(a) Schematic diagram of plate-fin heat sinks



(b) Photograph of the aluminum plate-fin heat sinks

Fig. 2 The aluminum plate-fin heat sinks components, including (a) schematic diagram of plate-fin heat sinks, and (b) photograph of the aluminum plate-fin heat sinks

**Table 1.** Characteristics of some commercially available thermoelectric

Parameters	TEG1-127-40-40-250 <sup>a</sup>
TE module sizes (mm)	40 x 40 x 3.7
Max. Operating hot-side temp.(°C)	250
Max. output power (W)	7.8
Max. output current (A)	1.5
Max. output voltage (V)	10.4
No. of couples	127
Module cost (US\$)	12

<sup>a</sup>Specification of TE Modules. Available from: <https://hong-lang.en.alibaba.com>. Accessed 4 April 2017

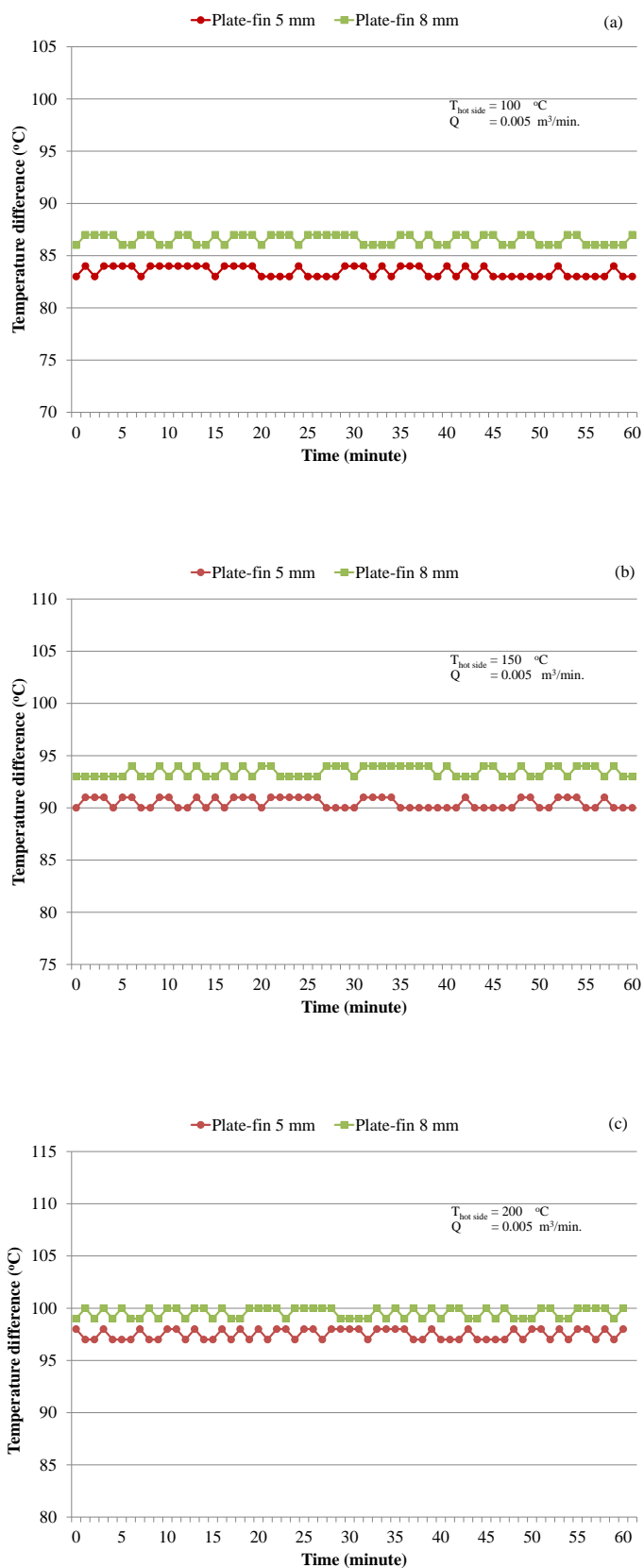
**Table 2** Dimensions of the plate-fin heat sinks

Channel	Size of the cooling block (mm)	Plate-fin height (mm)	Plate-fin thickness (mm)	Channel width (mm)
Aluminum	300x200x25	8	5	6
Aluminum	300x200x25	5	5	6

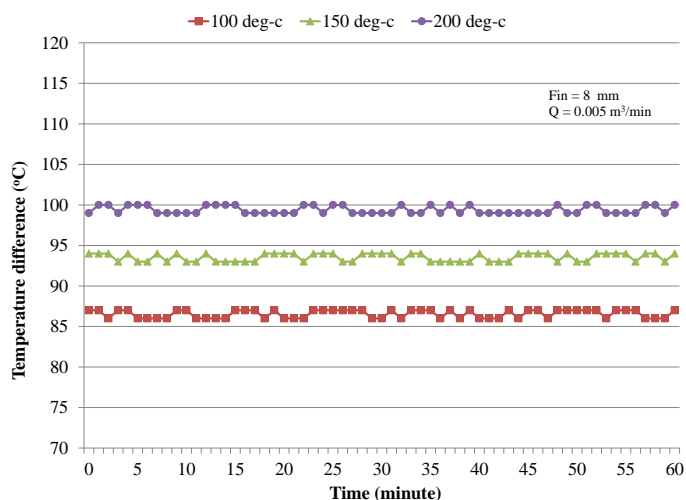
### 3. RESULTS AND DISCUSSION

In this experiment, the cold side surface of a TE power module was attached to the surface of an aluminum cooling block, while the hot side surface of a TE power module was attached to the surface of a heat source by an aluminum heat exchanger. Investigations were carried out by controlling the temperature on the hot side surface of the TE power module at 100, 150 and 200 °C. Thermoelectric generator efficiency measurements require quantifying the heat input temperatures to the hot side surface and the heat removed from the cold side surface and then removed to the plate-fin heat sink. Effects of a fin height on the plate-fin heat sink in terms of the temperature difference between the hot side surface and cold side surface of the TE power module for different temperature conditions are shown in Fig. 3. Due to the higher heat transfer area, the heat transfer rate from the hot side surface of the TE power module to the cold side surface and plate-fin heat sink increases. Therefore, the temperature difference between the hot side surface and cold side surface of the TE power module obtained from the plate-fin heat sink with a fin height of 8 mm was higher than that obtained with a fin height of 5 mm, especially for the hot side surface temperature at 200 °C. It can be seen from the figure that the temperature difference between the hot side surface and cold side surface of the TE power module for the hot side surface temperature at 200 °C (the fin height of 8 mm) is higher than the other temperature for the entire range of the period time, as shown in Fig. 4. Effects of the ethylene glycol coolant flow rate on the temperature difference between the hot side surface and cold side surface of the TE power module under the hot side surface temperature different conditions are shown in Fig. 5. For the three different coolant flow rates, a large temperature difference between the hot side surface and cold side surface of the TE power module is found for a larger coolant flow rate. The larger the temperature difference between the hot side surface and cold side surface of the TE power module, the more electrical current is produced and more power generated as a result.

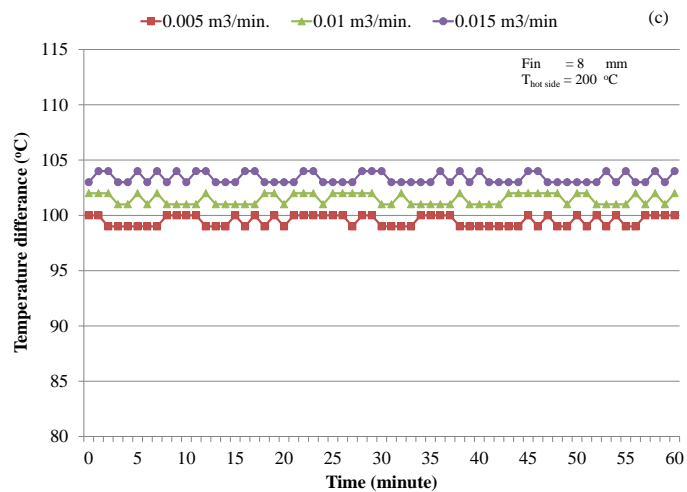
The temperature difference between the hot side surface and cold side surface of the TE power module obtained from the ethylene glycol coolant cooling for the plate-fin heat sink on the cold side surface of the TE power module was compared to water and air cooling methods, as shown in Fig. 6. It can be seen that an aluminum cold plate-fin heat sink with ethylene glycol coolant has a significant effect on the cooling of the TE power generator system. The power output of the TE power module obtained from the ethylene glycol cooling was compared to water and air cooling methods show that Fig. 7. It was found that the power output of the TE power module was about 8.9 W per module, which is higher than that of water cooling and air cooling. The relative error (%) for all the power output of the TE power module analyzed was less than 0.072%.



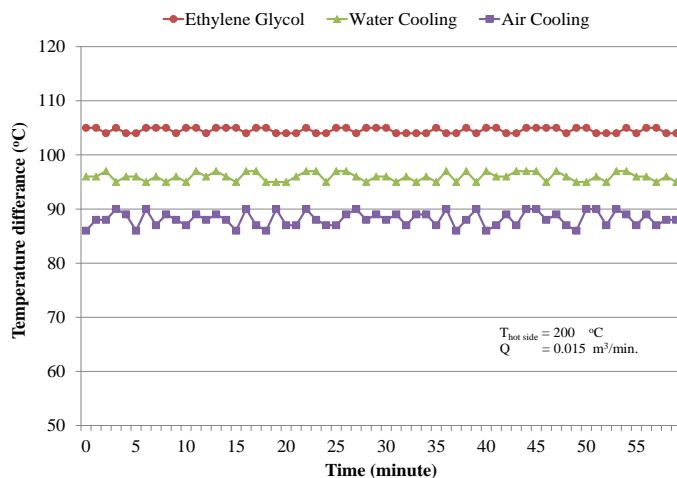
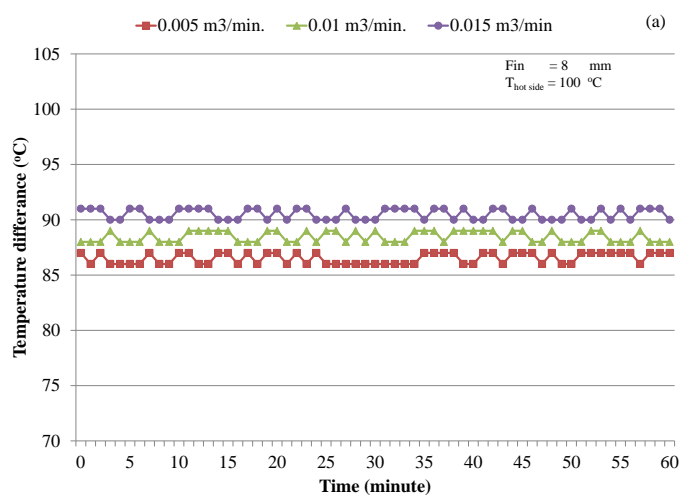
**Fig. 3** Effects of fin height on the temperature difference between the hot and cold sides of a TE power module for (a) hot side temperature of 100 °C, (b) hot side temperature of 150 °C, and (c) hot side temperature of 200 °C



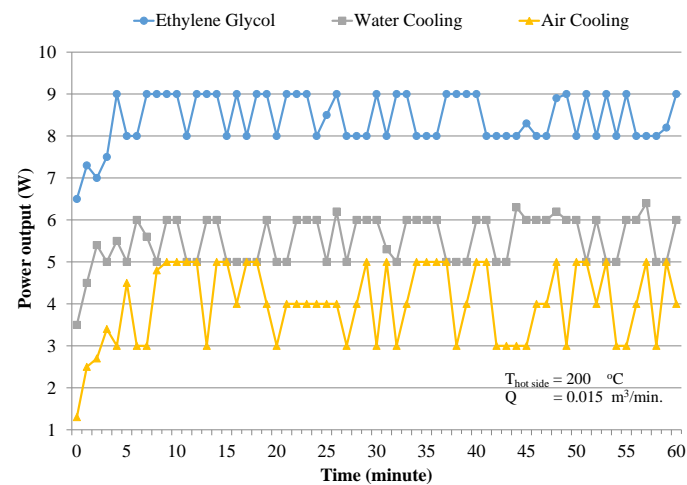
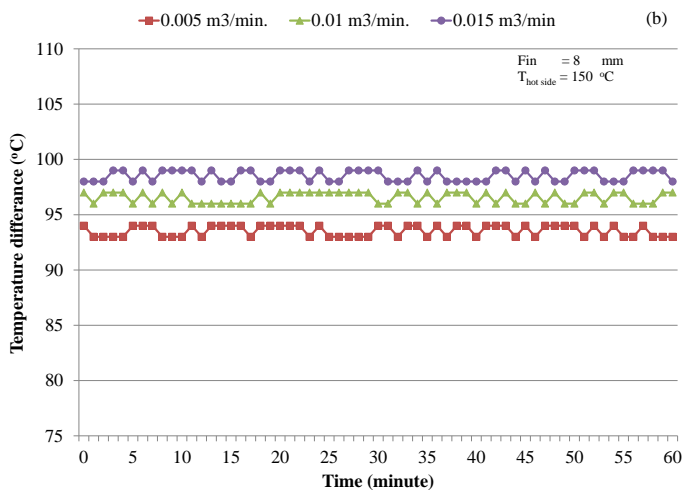
**Fig. 4** Variations of the temperature difference between the hot and cold sides of a TE power module with time for the hot side of the TE power module under different conditions



**Fig. 5** Effects of coolant flow rate on the temperature difference between the hot and cold sides of a TE power module for (c) hot side temperature of 200 °C



**Fig. 6** Effects of cooling technique on the temperature difference between the hot and cold sides of a TE power module



**Fig. 7** Effects of cooling technique on the power output of a TE power module

#### 4. CONCLUSIONS

Due to aluminum water cooling block liquid water cooler heat sink limits on the cold side surface of the TE power module with a higher temperature level, the heat transfer characteristics of a liquid flow through the plate-fin heat sink channels in the aluminum cooling block were investigated with ethylene glycol coolant as a working fluid. The effects of fin height for an aluminum plate-fin heat sink, the volumetric flow rate of the ethylene glycol coolant and the heat input condition for the total surface area of the hot side of TE power module on the temperature difference between the hot side surface and cold side surface of the TE power generator were considered. The results obtained from this experiment were compared to water and air cooling methods. It was found that the temperature difference between the hot side surface and cold side surface of the TE power module obtained from the heat sink with a fin height of 8 mm was higher than that obtained with a fin height of 5 mm and a higher coolant flow rate, especially with a hot side surface temperature condition at 200 °C. The larger the temperature difference between the hot side surface and cold side surface of the TE power generator, which is based on the Seebeck effect, the more electrical current is produced and more power generated as a result. The TE power module could generate a maximum power output of 8.9 W per module, which is higher than that of water cooling and air cooling. The results of this study are expected to be one of the interesting alternatives in the design of a cooling system for the TE power generator systems.

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