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The Utilization of Heat Pipe on Cold Surface of Thermoelectric with Low-Temperature Waste Heat

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Abstract. Thermoelectric (TE) modules are a thermo-element device that can harness the heat and convert it into electrical energy. As an electrical generator system, TE has several advantages i.e not noisy, easy maintenance, relatively small, lightweight and environmentally friendly because it does not produce pollution. In this paper, the research about the performance of TE modules that used for electric generator has been done. TE modules utilize low temperature waste-heat from a solar cell that simulated with a combination of a bulb and a collector plate. TE modules which tested are single and double modules, in which for double modules, connectivity Thermal-Series was used. Parameters of performance such as output power generated are determined by measuring the temperatures difference and the voltages difference at the test module as well as using several equations. The results show that the distance of heat source and load applied will greatly affect the performance of thermoelectric generator (TEG) modules. The results showed that the number of modules and loading will greatly affect the performance of TEG modules. The use of heat pipes generate a far greater power 4-6 times on the single TE Module (0.84 mW) than without heat pipe (0.14 mW), and a double TE modules that uses heat pipe will became 4 times larger (1.48mW) than without heat pipe (0.37mW).

Introduction

World demand for environmentally friendly technologies provides a big share in the use of thermoelectric generator (TEG) technology as an alternative energy source. TEG is a device that can convert waste of thermal energy into electrical energy. It has no mechanical device, not noisy and environmentally friendly [1-5].

As a device of electrical power generation, TEG works based on the Seebeck effect which was first discovered in 1821 by Thomas Johan Seebeck [6-9]. He showed that when two pieces of semiconductor material connected together in the environment with different temperatures then will arise an electrical current or electromotive-force on the material [7,8].

A number of studies of the TEG applications that utilize waste heat as input have been carried out by several researchers, among of them were the theoretical analysis for example by Chi [10] in which waste heat was used to run a TEG as approach model of a heat engine. While Eakburanawat et al. [11] in their research, have developed a battery charger based on thermoelectric generator principle. The developed system produces maximum power of 7.99 Watt. Furthermore Nuwayhid et al. [12] in their research developed and tested a TEG in a traditional stove in Lebanon. They used free convection in the side of TE modules and produced output power of 4.2 Watt. Likewise in their research, Hamade and Nuwayhid [13] also designed a single TEG module configuration for the application of waste heat from the burner combined with heat sink thermosyphonic of loop type. Also Champier et al. [14] used TE on biomass stove utilizing heat energy to produce electricity for fan and lighting. Still in connection with biomass stoves that use TE, Lertsatitthanakorn [15] applying it for a small radio or low power incandescent bulb. Putra et al. in the study, said that one way to absorb greater heat in the low-temperature heat source can be done by using heat pipes [16-18].

From the above description shows that leave open the possibility to perform analysis of TEG that use waste heat from lower temperature difference. One of them is the heat from a solar cell. The temperature difference between the below surface of solar cell and ambient temperature can be used to generate electromotive-force by placing thermoelectric on it.

Therefore the objective of this study was to know the characteristics of TEG when heat pipes is used to absorb heat on the cold side of TEG modules. In this case the TEG module combinated with a solar cell, where the TEG module is placed on the lower surface of the solar cell.

Experimental Method and Formulation

Experimental Set Up. To find the performance of thermoelectric module that utilize the waste-heat energy from solar cell was made the design of experiments as shown in figure 1. To avoid the erratic weather constraints during the experiments, sunlight was simulated by light that provided from a bulb and the lower surface of the solar cell was simulated by a collector plate which covered by styrofoam walls such that the heat losses will be wasted out to the environment as small as possible. On the below surface of the collector plate was affixed thermoelectric module that serves as device to convert the existing heat at the collector plate into electrical energy.

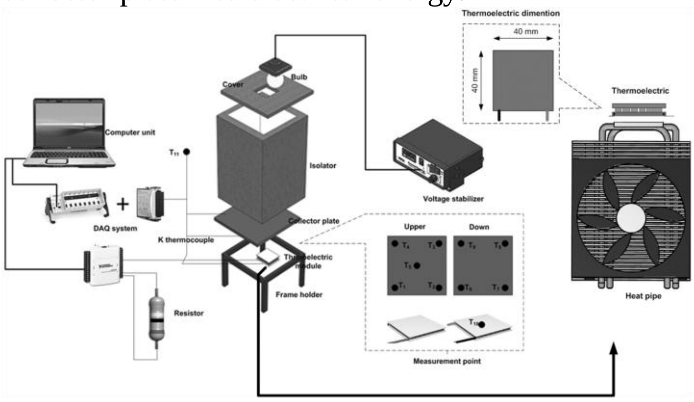

Fig. 1. Testing Installation of characteristics of TE Module with a Bulb as Heat Source

Testings were done by providing thermal energy from bulb were varied 50W, 150W and 300W with bulb power spacing of the collector plate was in distance 25 cm. Thermoelectric modules were used also varied in the amount (single and double) and the circuit was series thermally. While the variation of out load are constant for any amount and connectivity of TE modules.

The intensity of the light bulb was predicted by using a heat gauge the intensity of solar radiation (Piranometer). In this case, sensitivity of the Piranometer are 9 to 15 $\mu V/Wm^2$. Retrieval of acquisition data of temperatures and voltages were connected directly to the computer by using components which supported by LabView 8.5 program software National Instruments. Temperature measurements using thermocouple type K (accuracy of ± 0.01°C) with the NI-9213 module and voltage measurements using NI-6008 module.

In this testing, on the below surface of the collector plate affixed to the thermoelectric module (Fig. 1) which functioned as a system that will utilize heat (thermal energy) from the plate collector to generate electricity, in this case is the voltage which is resulted. The resulting voltage difference occurs because of temperature difference on the both sides of TE module, which is caused by the heat absorbed by the surface of the thermoelectric module which direct contact with the lower surface of the collector plate. While the below surface of the thermoelectric expected can release the heat as much as possible so that the temperature difference on the both surfaces of the thermoelectric is maximum. The release of heat on the lower surface of TE module is usually assisted by a heat pipe as a cooling system.

Performance of TE Module. In analyze the performance TE modules, the Seebeck coefficient which describe of voltage (electromotive force) arising due to the temperature difference becomes very important. The Seebeck coefficient can be expressed by the following equation [3,16]:

$$\alpha = \frac{\Delta V}{(T_h - T_c)} \quad (1)$$

where:

ΔV = voltage difference between junction [V]

α = Seebeck coefficient between two semiconductor materials, P and N [V/°C].

Th:Tc = temperature of the thermocouples on hot side and cold side [°C]

While the generated electric current is given by the following equation [9,17]:

$$I = \frac{\alpha \times \Delta T}{R_i + R_L} = \frac{\alpha \times (T_h - T_c)}{R_i + R_L} \quad (2)$$

where:

I = electric current flowing in the circuit [A]

R_i = internal load of the thermoelectric generator module [Ω]

R_L = external load [Ω]

ΔT = Th-Tc

The rate of heat transfer (Q_h) coming from the heat source at temperature T_h (hot junction) to the cold surface at a temperature Tc (cold junction) is as follows [9]:

$$Q_h = (\alpha I T_h) + K(T_h - T_c) \quad (3)$$

where K is the thermal conductance of the module element [W/°C].

Total output power (P) which generated to counter the outside load [9] and the efficiency (η) of thermoelectric generator are as follows [18]:

$$P = I^2 R_L \quad (4)$$

Power in equation (4) will achieve the maximum value when the external load R_L is equal to the internal load Ri of the thermoelectric generator [9].

Result and Discusion

Parameters of testing which became focus of observations respectively ie: the temperature difference (ΔT), the voltage difference (ΔV), and output power (P). In this paper the results of measurements and calculations displayed in the form of graphs and will be demonstrated of charts within the effect of variation input power and loading with a constant heat source distance.

Single TE Module. The results of measurements of the temperature difference (ΔT) for voltage measurement (V) together with the output power (P) for single TE module is shown in figure 2.

It appears that the greater the power input the greater temperature difference (ΔT) obtained. This is because the greater heat input, the upper and lower surface temperature of the collector plate (Th) will increase and the TE surface temperature (Tc) also remained relatively constant due to the heat pipe cooling provided. At 50W, the temperature difference ranges from 8.17 ÷ 8.78°C, for 150W input power ranges from 18.84°C ÷ 22.00°C and to 300W input power ranges from 42.28°C ÷ 46.07°C.

As the temperature difference (ΔT) produced increasing , it was also seen an increase in power output generated, this is due to the increased voltage obtained (see figure 2). The greatest value of power output generated for the power input 300W with a 10Ω load was 16.46mW, while for load 47Ω, 100Ω and 1kΩ 12.70mW, 8.14mW and 0.96mW respectively. Because the resistor in single TE module used is about 5 Ω in unused condition (cold) then the true value of the generated power output is close to a statement given by Goldsmid [9] as written above that maximum useful power is achieved when the external load equal to load in thermoelectric generator modules.

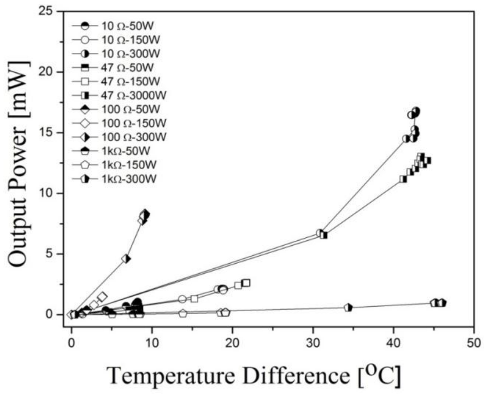

Fig. 2. ΔT - P of Single TE

Double TE Modules

In this section we explore the results for the double TE module with thermally serial connectivity. In this connection, two pieces single TE module were stacked so that the module thickness increased, which means that the thermal resistance conductivity will decline. Thus the expected temperature difference (ΔT) that occur will be greater than the single TE module.

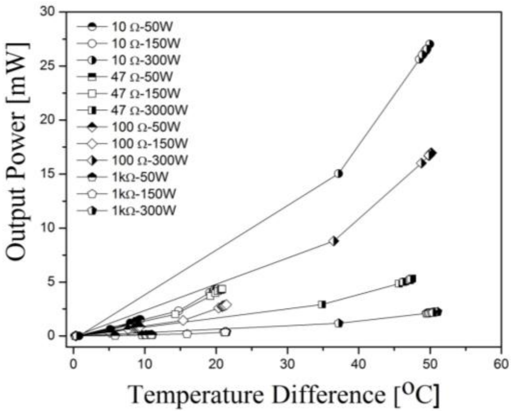

Fig. 3. ΔT- P of Double TE

Figure 3 shows the results of measurements of the temperature difference (ΔT) of the output power generated. As in figure 2, it also displays the results for the 3 variations of the input power and 4 external load variations with distance to the heat source of constant collector plate. With the addition of input power causes an increase in the temperature difference (ΔT). The same phenomenon occurs in a single TE module. Likewise, the addition of external loading increases the temperature difference (ΔT). Temperature difference (ΔT), the highest achieved at 300W input power in the range 47.28°C ÷ 51.03°C, while 150W range ΔT at 20.20°C ÷ 21.46°C and ΔT at 50W input power range 8.95°C ÷ 10.95°C.

In Figure 3, it is seen that the greater provision of input power will increase the difference in temperature and power output, but with the addition of external load (R_L) will provide a reduction in the amount of power output raised. The maximum generated output power happened to 300W input power to the load (R_L) that 27.03mW 10Ω while to load 47Ω, 100Ω and 1kΩ ranges for each 5.27mW, and 2.18mW 16.72mW. These results further confirm the equivalence between the voltages obtained with power that can be generated from a thermoelectric module.

Just as in a single module, we see that the maximum power transfer theorem is valid for double modules since 10Ω load still gives the greatest output power which ranges from 27.03mW.

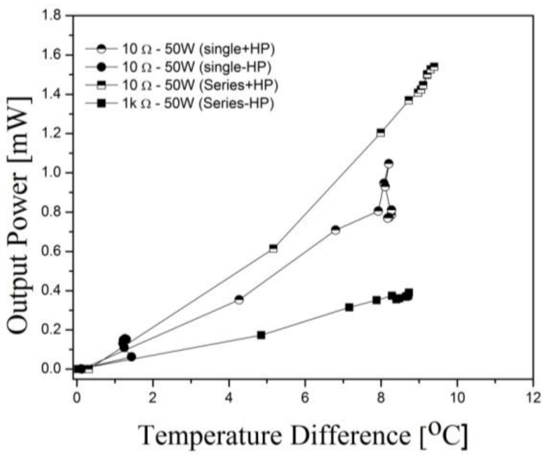

Fig. 4. ΔT- P of Single and Double TE modules

Figure 4 shows a chart comparison between the results of a single TE module and double TE modules for input power 50W and external 10Ω load either using heat pipes or without heat pipes. Clearly seen in the Figure that the power output can be generated in a single TE module uses heat pipes are around 6 times greater (0.84mW) compared to that of a single TE module without a heat pipe (0.14mW), and the double TE modules that uses heat pipes becomes 4 times greater (1.48mW) compared to the double TE modules without heat pipe (0.37mW).

Summary

In this study, the results can be summed up: The heat source with a greater power input will increase the temperature difference between the hot side and the cold side of the TE module, the cold side temperature is maintained close to ambient air temperature. Additional external loading decreases the amount of power generated. Doubling the TE module will increase the power output of about 2 times greater (1.48mW) compared to that of output power generated by a single TE module (0.77mW). The use of heat pipes can generate a far greater power 4-6 times on the single TE Module (0.84mW) than without heat pipe (0.14mW), and a double TE modules that uses heat pipe will became 4 times larger (1.48mW) than without heat pipe (0.37mW).

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