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# Improved Performance of a Radiative-Based Thermoelectric Power Generator with Vertical Finned Absorber: An Experimental Investigation

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**ABSTRACT**

This paper is an extension of our previous research aimed to improve the performance of radiative-based thermoelectric power generator concept through the use of vertical finned absorber instead of horizontal one (TEG-RVFA). To this end, we used the experimental setup developed in previous study and modified it according to the objective of this paper. The TEG-RVFA is composed of a heated plate (297 mm×182 mm) and four sets of vertical finned absorbers (41 mm×55 mm) with 40×40 mm thermoelectric modules to absorb the heat emitted. At the back side, a finned aluminum heat sink 119 mm wide and 200 mm length with two DC fans was used for cooling. The electrical power supplied to the heater varied between 1000 - 1400 watts and the air gap between the heated plate and the finned absorber varied between 1 to 5 cm. Data recorded included the generated voltage, current, and temperatures at various locations. Results are also compared to those published earlier with horizontal finned absorber. It was observed that the electrical current generated varied like in the case with horizontal finned absorber (TEG-RHFA); it increased with the power supplied and reducing the air gap space. However, the TEG-RVFA led to better performance. The maximum power generated and the temperature difference between the hot and cool sides of thermoelectric modules observed at 1400 Watt and 3 cm air gap space were 1.63 Watt and 73.85°C compared to 0.78 Watt and 58.93°C for TEG-RHFA. The maximum power generation efficiency is 7.4% with horizontal fins and 9.1% for vertical finned absorber. This improvement is due to better heat transfer due to induced air circulation between the fins reducing heat accumulation at the base of the absorber and creating higher temperature difference between the two sides of thermoelectric modules. Therefore, TEG-RVFA is recommended for use when considering application in waste heat recovery such as furnaces and chimneys.

## 1. INTRODUCTION

It is well admitted that a large amount of heat is wasted during manufacturing process in industries by different machines and equipment used. Often, an important part of this heat is released to the atmosphere directly through different means and forms that affect the environment considerably. Researchers and engineers worldwide developed various systems to collect this wasted heat such as primary heating, heat storage, drying etc. In addition, today energy cost increased significantly due to political tensions and military confrontations. Countries in various parts of the world issued strict measures and recommendations to limit the use of energy and control the impact on economic growth.

Under such circumstances and worries about the price of energy in the future, waste heat recovery is gaining renewed attention. The last decades have seen accelerated development for the use of thermoelectricity in order to recover heat and convert it into electrical energy using Seebeck effect [1]. Various sources of heat can be used to generate electrical current such waste heat from industries [2-4], cooking biomass stove [5], solar collectors [6-8], hybrid systems [9-11], cooling [12] and air-conditioning [13]. An interesting application to collect waste heat based on radiative heat exchange was first proposed by Watcharodom et al. [14]. Next, our team improved the performance of concept introduced in the study of Watcharodom et al. [14] by using a horizontal finned absorber and air for cooling instead of water adopted by Watcharodom et al. [14]. Results are published in the study of Thanthong et al. [15].

This paper aims to conduct experimental investigation of the use of vertical finned heat absorber on the performance of thermoelectric generator using radiative heat exchange and compare results to those obtained with horizontal finned absorber.

## 2. EXPERIMENTAL METHODOLOGY

To conduct our investigation, we used the experimental setup developed in the study of Thanthong et al. [15] and modified it according to the objective of this paper. The TEG-RVFA is composed of a heated plate (297 mm×182 mm) and four sets of vertical finned absorbers (41 mm×55 mm) with 40×40 mm thermoelectric modules (MT2-1,6-127) to absorb the heat emitted. At the back side, a finned aluminum heat sink 119 mm wide and 200 mm length with two DC fans was used for cooling. The electrical power supplied to the heater varied between 1000-1400 watts and the air gap between the heated plate and the finned absorber varied between 1 to 5 cm. The four lateral sides of the absorber assembly was well insulated to prevent heat transfer to the cooling heat sink. The various components were assembled and mounted on a metallic structure. Figure 1 shows a picture of the experimental setup (top) and the geometry and dimensions of assembled vertical finned heat absorber (bottom).

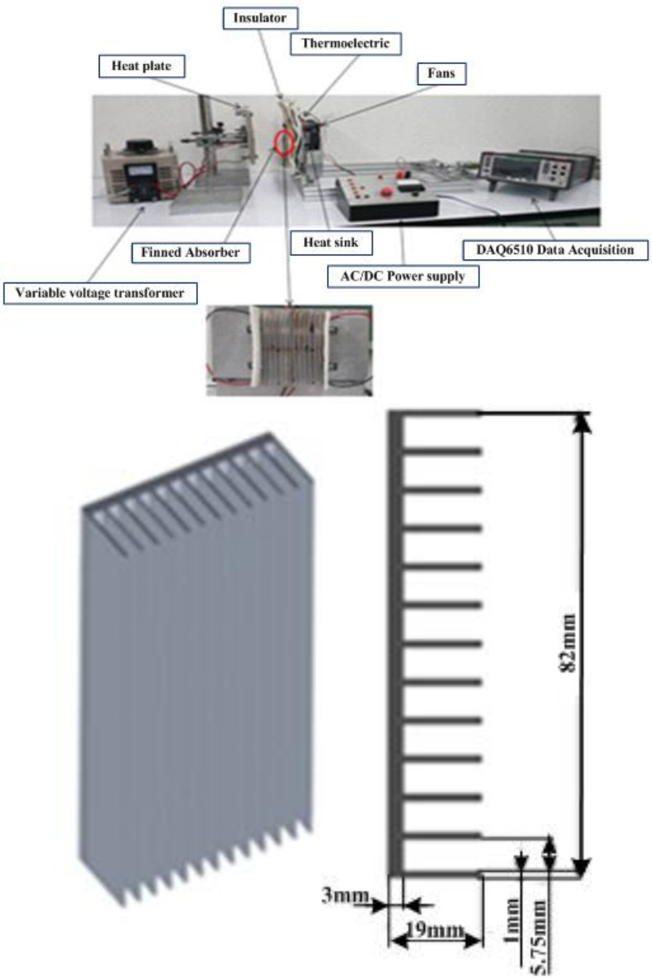



**Figure 1.** The experimental setup (top) [15] and geometry and dimensions of the RVFA (bottom)

The tests were conducted for the same conditions considered in the study of Thanthong et al. [15]. Temperatures at various positions and electrical current generated were measured following the method reported by Thanthong et al. [15]. Each test lasted 60 minutes and data were recorded continuously. For more details about the experiemntal setup, procedure, measuring devices refer to the study of Thanthong et al. [15]. The specifications of thermoelectric module MT2-1,6-127 are given in Table 1.

**Table 1.** Specifications of thermoelectric module MT2-1,6-127

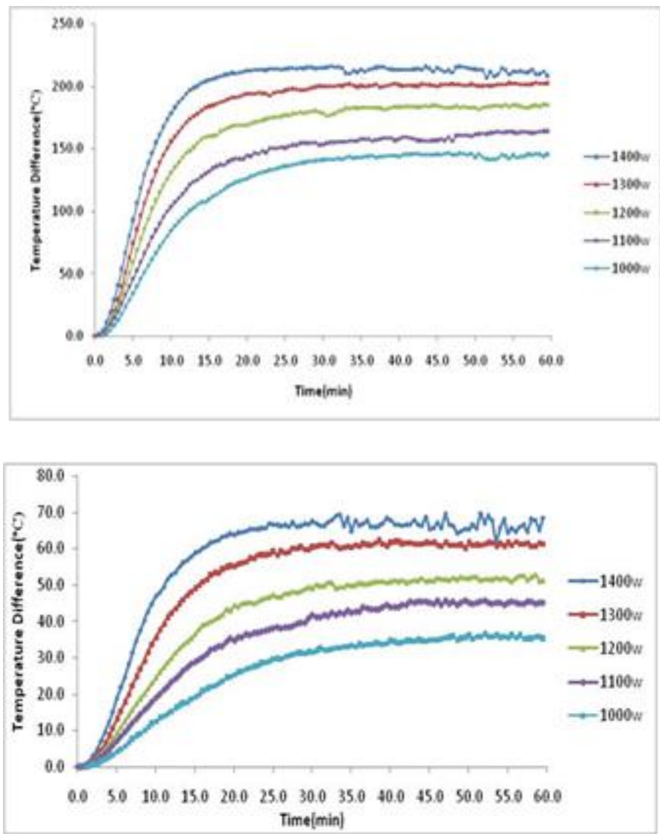
| Parameter | Cooling Module |
|---|---|
| Leg height (mm) | 1.2 |
| Area of the thermoelement $(mm)^2$ | 1.96 |
| Contact height (mm) | 1.0 |
| Insulator plate thickness (mm) | 0.63 |
| Module height (mm) | 4 |
| Area to length ratio | 1.63 |
| No. Of couple (number) | 127 |
| Maximum operating hot side Temperature (°C) | 135 |

## 3. RESULT AND ANALYSIS

For simplicity of presentation, the two configurations of Radiation-based Thermoelectric Generator with Vertical and Horizontal Finned heat Absorber are referred to as TEG-RVFA and TEG-RHFA respectively.

### 3.1 Temperatures variations

Figure 2 illustrates an example of the temperature differences of the TEG-RVFA between the heated plate and top of fin, top and base of vertical fins and the two sides of thermoelectric modules at 3 cm air gap under the power supply considered.



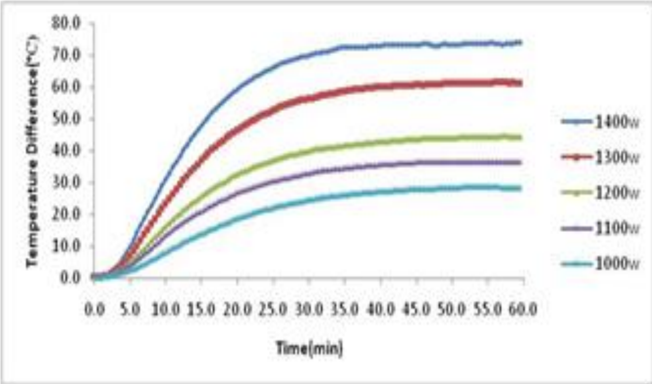



**Figure 2.** Measured parameters variations versus time at 3 cm air gap: temperature difference between heated plate and top of vertical fin (top), top and base of vertical fin (middle) and two sides of thermoelectric module (bottom)

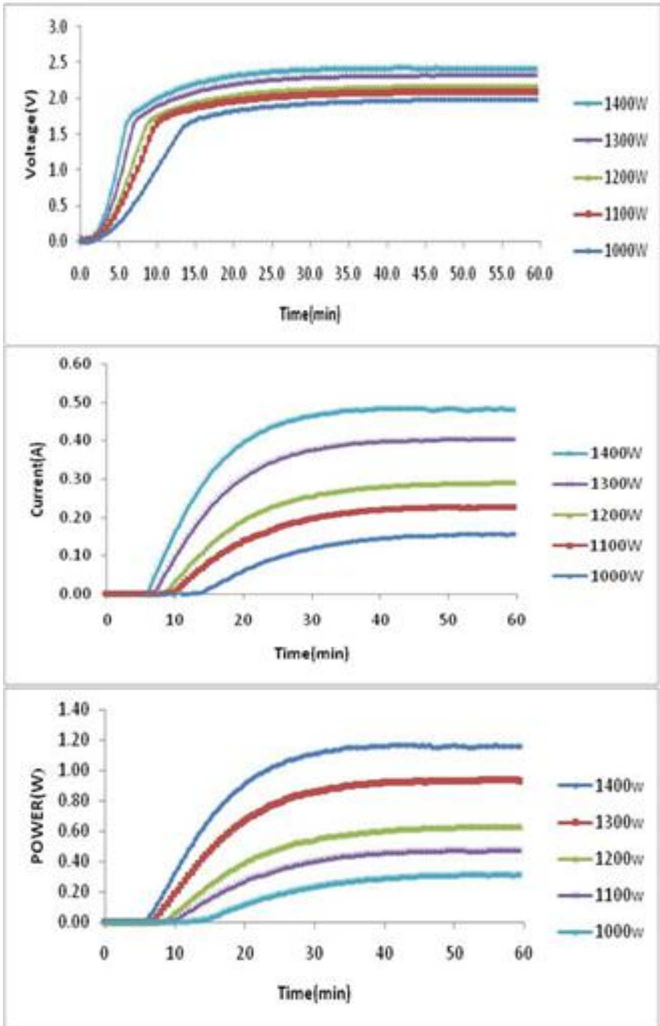



**Figure 3.** Variations of measured electrical parameters versus time for the various power applied at 3 cm air gap

It can be seen that all measured temperature differences increased till reaching a relatively steady state condition. These temperature differences and the time required to attein steady condition increase with the amount of electrical power applied to the heater. These variations are similar to those observed with TEG-RHFA. However, the temperature difference between the hot and cold sides of thermoelectric modules are significantly higher when compared to those observed with the TEG-RHFA (Figure 5 [15]). This is due to the induced air circulation between the fins that improve heat transfer between the vertical fins and reduce heat accumulation at the base of the absorber leading therefore to higher between the two sides of thermoelectric modules.

### 3.2 Voltage, electrical current, power generated

Figure 3 shows that the measured voltage increased continuously for about 15-20 minutes then remained constant whereas the measured current and power needed longer time about 30-35 minutes to stabilize. This is a normal observation as voltage stabilizes faster than current when considering such measurement and longer time is needed to attain stable state when higher power is applied.

### 3.3 Comparison of performance between TEG-RVFA and TEG-RHFA

Figures 4 and 5 show the measured voltage, current and power generated for the test conditions considered of TEG-RHFA and TEG-RVFA respectively.

Tables 2 and 3 summarize the different measured electrical parameters of TEG-RFA and TEG-RVFA for the range of electrical power supplied to the heated plate. It can be seen that TEG-RVFA could generate higher electrical power when compared to the TEG-RHFA. This is due to the improved induced ventilation between the vertical fins that lower heat accumulation in the fins which in turn create higher temperature differences between the hot and cold sides of TE modules leading to better performance of electrical current generation.

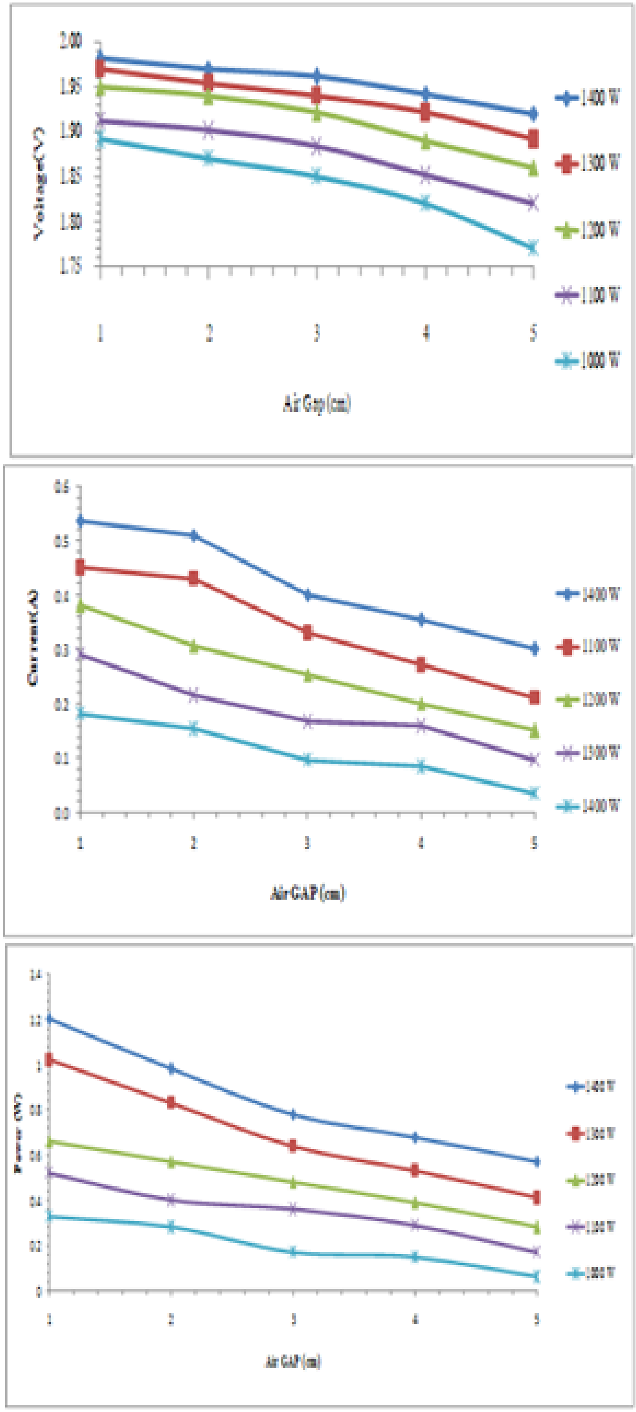
**Table 2.** Electrical voltage, current and power generated for the range of electrical power supplied to the heater at steady conditions of TEG-RHFA

| Air Gap (cm) | TEG-RHFA | | |
|---|---|---|---|
| | **Voltage (V) (1000-1400W)** | **Current (A) (1000-1400W)** | **Power (W) (1000-1400W)** |
| 1 | 1.89-1.98 | 0.18-0.57 | 0.33-1.2 |
| 2 | 1.87-1.97 | 0.15-0.51 | 0.28-0.98 |
| 3 | 1.85-1.96 | 0.095-0.40 | 0.17-0.78 |
| 4 | 1.82-1.94 | 0.084-0.35 | 0.15-0.68 |
| 5 | 1.77-1.92 | 0.35-0.30 | 0.06-0.57 |

**Table 3.** Electrical voltage, current and power generated for the range of electrical power supplied to the heater at steady conditions of TEG-RVFA

| Air Gap (cm) | TEG-RVFA | | |
|---|---|---|---|
| | **Voltage (V) (1000-1400W)** | **Current (A) (1000-1400W)** | **Power (W) (1000-1400W)** |
| 1 | 2.08-2.55 | 0.22-0.41 | 0.46-1.54 |
| 2 | 2.03-2.47 | 0.19-0.52 | 0.38-1.31 |
| 3 | 1.97-2.41 | 0.15-0.48 | 0.30-1.15 |
| 4 | 1.92-2.32 | 0.11-0.40 | 0.22-0.93 |
| 5 | 1.89-2.29 | 0.10-0.38 | 0.19-0.88 |

The efficiency of TEG-RVFA and TEG-RHFA is calculated as the ratio between the power generated and the radiative heat transferred from the heated plate to the finned absorber following the method adopted in the studies of Watcharodom et al. [14] and Thanthong et al. [15]. They are compared in Table 4 for the various air gaps at 1200W.



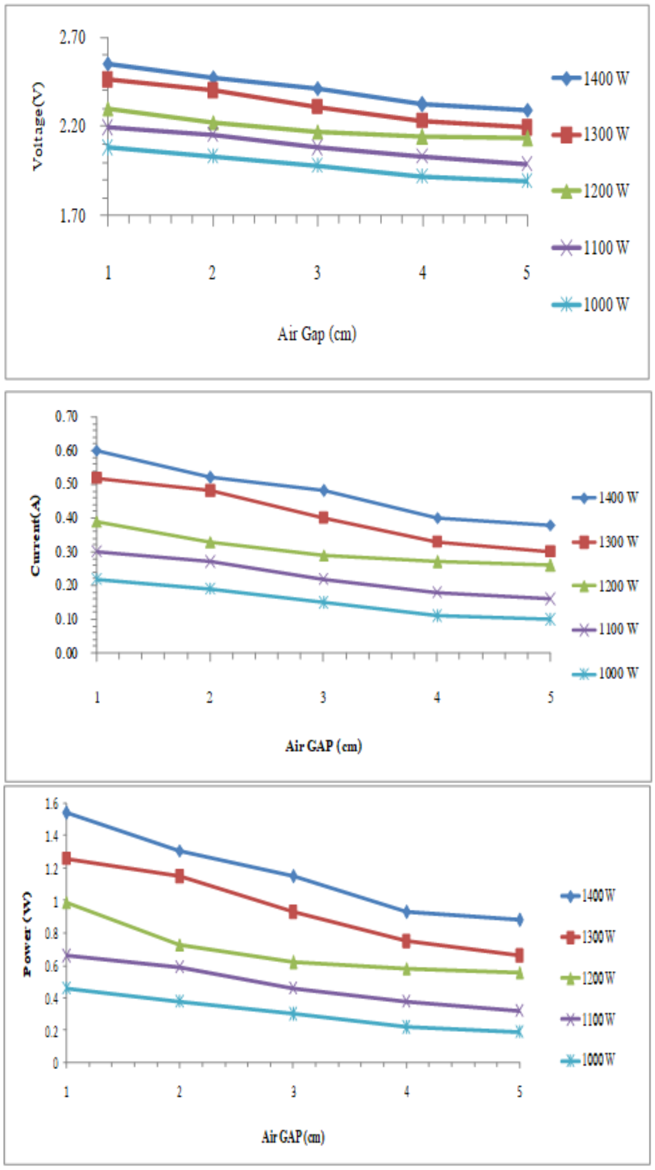

TEG-RFA

**Figure 4.** Variations of measured electrical parameters versus time for the different power supplied and air gap considered at steady conditions of TEG-RFHA

**Table 4.** Comparison between efficiency of TEG-RHFA and TEG-RVFA for different air gaps and 1200W constant power supply at steady conditions

| Air Gap (cm) | Efficiency of RHFA | Efficiency of RVFA |
|---|---|---|
| 1 | 0.0748 | 0.108 |
| 2 | 0.0737 | 0.106 |
| 3 | 0.0696 | 0.101 |
| 4 | 0.0602 | 0.096 |
| 5 | 0.0462 | 0.070 |

It can be observed that the shorter the air gap, the higher is the efficiency for the two fin configurations and highest efficiency is obtained with vertical fins. Therefore, the use of vertical fins can lead to better performance of the radiative-thermoelectric power generator concept and is recommended when considering application in waste-heat recovery in industries and different energy systems.




TEG-RVFA

**Figure 5.** Variations of measured electrical parameters versus time for the different power supplied and air gap considered at steady conditions of TEG-RVHA

## 4. CONCLUSION

Experimental performance comparison of radiative-based thermoelectric power generator between vertical and horizontal finned absorbers is reported and discussed using a lab-scale setup. The electrical power supplied to the heater varied between 1000 to 1400 watts and the air gap between the emitted plate and the finned absorber varied between 1 to 5 cm. Decreasing the air gap and increasing the power applied improved the generated electrical current. It was demonstrated that the vertical finned absorber led to better performance compared to the horizontal one. This improvement is due to better heat transfer due to induced air circulation between the fins reducing heat accumulation at the base of the absorber and creating higher temperature difference between the two sides of thermoelectric modules. Under test conditions, at 1cm air gap and 1200 Watt power supplied to the heater, the maximum generation efficiency is about 7.4% with horizontal finned and 10.8% for the vertical one. This is due to better heat transfer and less heat accumulation due to the induced air circulation between the vertical fins. Despite its limited efficiency, the proposed concept is interesting as there is no contact between the emitted source and the thermoelctric generator.

Therefore, vertical finned heat absorber is recommended when considering application of radiative-based thermoelectric power generation in waste-heat recovery such cement kilns, exhaust chimneys and industrial plants. A large scale investigation of the concept proposed needs to be elaborated to investigate its reliability and economic feasibility.

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