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Power generation from waste heat using Heat Pipe and Thermoelectric Generator

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Abstract

This paper presents the investigation of power generation using the combination of heat pipes and thermo-electric generators. A majority of thermal energy in the industry is dissipated as waste heat to the environment. This waste heat can be utilized further for power generation. The related problems of global warming and dwindling fossil fuel supplies has led to improving the efficiency of any industrial process being a priority. One method to improve the efficiency is to develop methods to utilize waste heat that is usually wasted. Two promising technologies that were found to be useful for this purpose were thermoelectric generators and heat pipes. Therefore, this project involved making a bench type, proof of concept model of power production by thermoelectric generators using heat pipes and simulated hot air.The laboratory experiment of the proposed system was obtained with a counter flow air duct heat exchanger. The results obtained show an increase in the ratio of mass flow rate in upper duct to lower duct has a positive effect on the overall system performance. A higher mass flow rate ratio results in a higher amount of heat transfer and higher power output. The proposed system can be used for waste heat recovery from the industry where thermal energy is used in their daily process.

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Keywords: Power generation; Waste heat; Heat pipes; Thermoelectric generator

1. Introduction

Growing demand for energy consumption has become a major problem facing the world today. It is estimated that globally, only one third of all energy usages were utilized while the remaining is rejected as waste heat. A large part of global energy usage is consumed in the form of thermal energy [1]. This has triggered off an intriguing challenge for scientists and engineers to utilize the waste heat from the industry. Thermo-electric generator (TEG) is a solid state device capable of converting thermal energy to electrical energy. There are no moving parts in TEG and therefore no maintenance is required for long operation [2]. The use of heat pipe can transfer a large amount of heat over a relatively long distance due

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to its high thermal conductivity [3]. It is very effective and simple device because of its uncomplicated configuration, no power input requirement, no moving parts, passive heat transferring, compactness and lightweight. There are many ongoing researches on thermoelectric power generation undertaken in many countries such as U.K., the U.S., Ukraine, Australia, Korea and Japan [1]. This study will provide a continuous research on thermoelectric power generation that will not only lead to an improvement in its feasible performance solutions, but also to the future prospect of promising energy conservation technology.

Nomenclature

$P_{Elec\ TEG}$	Electrical power of thermoelectric generator [W]
$\dot{Q}_{max}$	Maximum heat transfer rate [W]
Q_H	Heat input into module [J]
Q_C	Heat removed from the cooled side [J]
R	Thermal resistance [˚C/W]
R_{total}	Total thermal resistance [˚C/W]
T	Temperature [˚K]
ΔT	Temperature difference [˚C]
$\dot{m}$	Mass flow rate [Kg/s]
C_p	Heat capacity [J/˚K]
TEG	Thermoelectric generator
HPTEG	Heat pipe and Thermoelectric generator
Greek symbols	
μ_{TEG}	Conversion efficiency [%]

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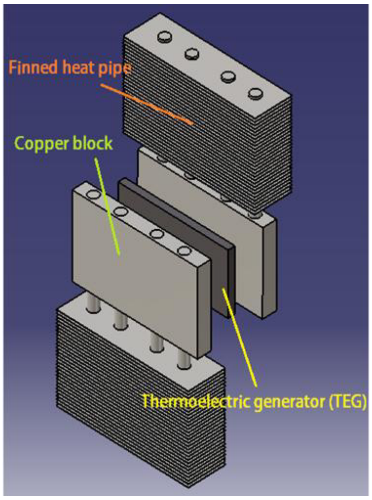
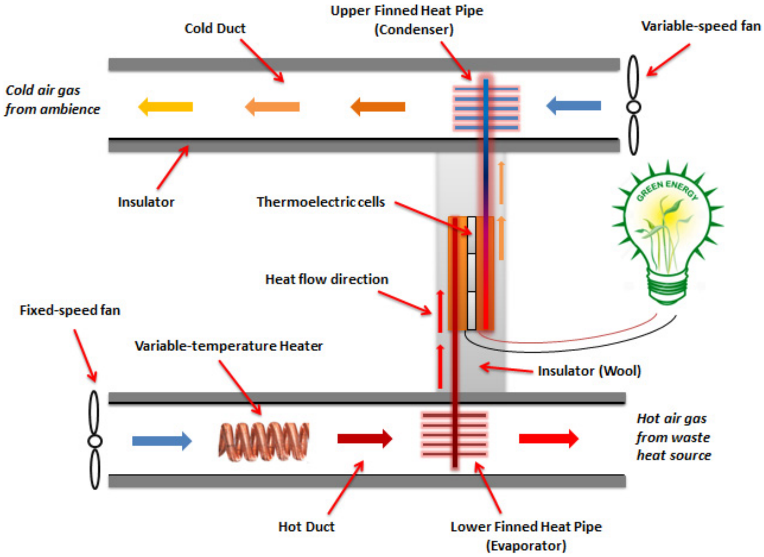
2. Description of the proposed system

A concept of power generation system using heat pipe and thermoelectric generators was developed uniquely for waste heat recovery based on counter-flow type system in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University [4]. The system is composed of TEG sandwiched between two copper blocks containing 4 heat pipes to transfer the heat from lower duct to heat up one side of TEG and then discharge the heat to upper duct such that the other side of TEG is cooled down. The air flowing through the duct is facilitated by the fans placed at the inlet of the two ducts. The variable-speed fan is placed at the inlet of the upper duct while the fixed-speed fan is placed at the inlet of lower duct. The heat source in lower duct is supplied with a variable-temperature heater placed next to the fixed-speed fan in order to heat up an incoming air to the heat pipes. Due to the heat transfer from the lower and the upper duct of the system, the temperature difference between the TEG will result in power generation due to the temperature gradient [2]. Furthermore, the designed system will likely enable a high recovery ratio of waste heat since the temperature of flowing air over lower heat pipe is increased by the preheated air from the upper heat pipe [4]. The module of thermoelectric cell sandwiched by copper blocks and the proposed concept of the counter-flow type system is illustrated in Fig. 1. The advantage of this system is that the ability of the heat pipe to transfer heat in a passive mode without any moving components allows for a low maintenance system for a long period of time.





(a) (b)

Fig. 1. (a) Module of heat pipe and thermoelectric generator [5] ; (b) The concept of power generation from waste heat using heat pipe and thermoelectric generator [4].

3. Experimental method

Figure 2 below shows an experimental test rig that used for the experiment. The setup was designed to accommodate 8 modules of TEG sandwiched between two copper blocks. Each module consists of 4 heat pipes and 6 thermoelectric generator (TEG) (40mm x 40mm). The heat pipes are attached with 62 rectangular fins.

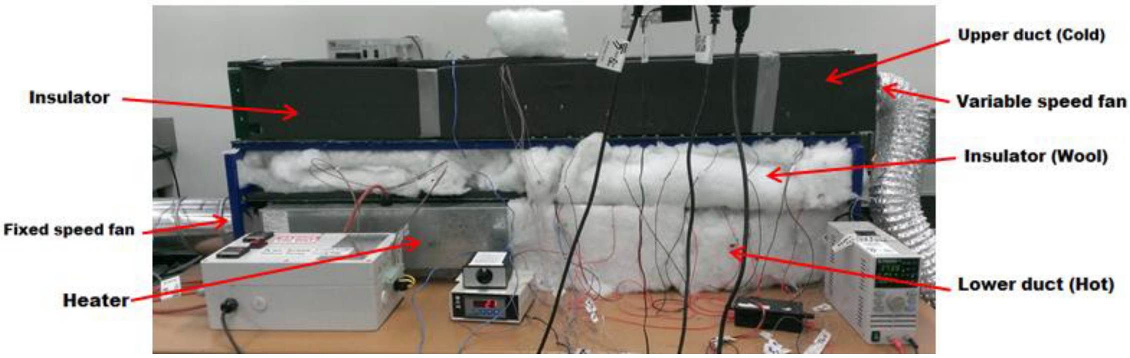


Fig. 2. Experimental rig used for testing

In the experimental set up, the Agilent data logger was used to record the stable state data of the air temperature and the electrical power generated by the system which can be converted automatically to a readable computer file. The heat source was supplied with a copper coil-heater set at the temperature of 108˚C. Experiment of test rig was performed over a range of airspeeds in the upper duct. An output of open circuit voltage was obtained by adjusting the external resistance gradually to attain the maximum power output of the system. The external resistance applied to the system were varied 500 Ohm to 50 Ohm.

The electric power generation for the system can be written in the following formula [3]:

$$P_{elec\,TEG} = \mu_{TEG}\dot{Q}_{max} \tag{1}$$

where Q_{max} is the total rate of heat transfer through a counter-flow heat exchanger duct of the system. The power conversion efficiency can be determined by the ratio of the generated electrical power of TEG and the heat input into the module (Q_H) [6]:

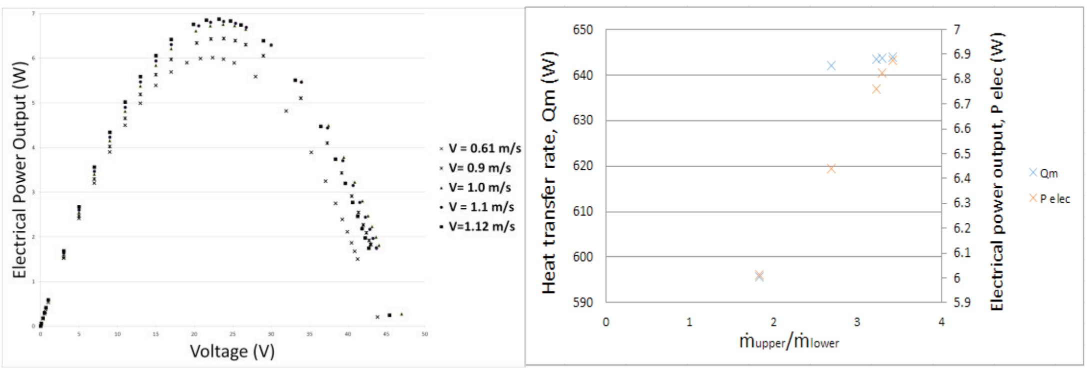
$$\mu_{TEG} = \frac{P_{elec\,TEG}}{Q_H} \cong \frac{P_{elec\,TEG}}{Q_C + P_{elec\,TEG}} \tag{2}$$

The term (Q_C) is the heat removed from the cold side, which is defined as:

$$Q_C = \dot{m}C_p\Delta T \tag{3}$$

4. Experimental results

The result of the output power versus voltage for different air velocity and the result of heat transfer rate versus maximum power output at different mass flow rate ratio are shown in Fig. 3 below. It can be seen that total power produced by the system increases when external load resistance were increased. The peaks at each plot again indicate the maximum power of the system which implies the external resistance and internal resistance of TEG has been equalized. It is noted that the velocity of air flowing in the upper duct was increased from the lowest to the highest. Accordingly, the first velocity shown in the graph is the lowest airspeed while the last velocity is the highest airspeed. From the result in the figure 3 (b), it is evident that there is a significant rise in the rate of heat transfer and maximum power output when the ratio of mass flow rate in upper duct over mass flow rate in lower duct is higher.



(a) (b)

Fig. 3. (a) Power output produced by the system versus voltage at different air velocity; (b) Heat transfer rate and maximum power output with respect to the ratio of mass flow rate

5. Conclusion and Recommendation

This research generates a novel concept of the power generation from waste heat using a combination of heat pipe and thermoelectric generator with investigations into key performance parameters such as maximum power output and heat transfer rate. The experimental result shows that an increase in the ratio of mass flow rate in upper duct to lower duct has a positive effect on the overall system performance. A higher mass flow rate ratio results in a higher amount of heat transfer and greater power output.

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Biography

Muhammad Fairuz Remeli holds MSc. Energy Conversion and Management from the University of Applied Sciences Offenburg. He is also a lecturer in the mechanical department, Universiti Teknologi MARA (UiTM), Malaysia. Currently enrolled as a Ph.D. student at RMIT University, Melbourne, his main research focuses on recovering heat from industrial waste heat.