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The Effects of Temperature Difference and Compressive Force to the Electrical Characterization of Peltier Cell for Artificial Concentrated Solar Power Thermoelectric Application

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ABSTRACT

Concentrated thermoelectric generating system uses concentrated solar radiations as passive heat source to operate the thermoelectric module for thermoelectricity generation. The pre-perquisite of thermoelectric effect is to provide a temperature difference across the thermoelectric cell by installing active water-cooling device on the opposite side of the heated panel. Thermoelectric cells are known to have low energy conversion (3-5%) hence optimizing the parameters associated with the operation of the thermoelectric cells is very important to improve the overall system efficiency. Thermal contact interfacial tests were carried out to determine the optimum compressive stress for greater thermoelectric power generation as well as to avoid cell damage under mechanical compression. In this paper, a series of parametric studies for output power, output current, output voltage and open circuit voltage were conducted indoor on a Peltier-type thermoelectric cell to investigate the

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thermoelectric performance under different conditions. The aim of this study is to achieve optimum setting prior to the development of the final test rig which will be tested outdoor. The indoor experiments have shown that there is a limit to the overall cooling water flow rate and the compressive force applied to the thermoelectric cells under optimal operation. At the optimal parametric consideration of 11.11 ml/s cooling water flow rate and 245.25 kPa compressive forces, the thermoelectric cell was able to produce output power of 4.19W while operating at temperature difference of 94.55°C and efficiency of 2.62% (21.88% of Carnot efficiency).

Keywords: *Thermoelectric cell, concentrated thermoelectric power system, Peltier cell, renewable energy, Seebeck effect*

Introduction

Concentrated thermoelectric generating (CTEG) system is among the viable sustainable power generators which utilizes concentrated solar flux for thermoelectric power generation. The power generating module in the CTEG system uses thermoelectric cells (TECs) for direct thermal-to-electrical power conversion. The TECs are not only noise free in operation, but there are also no moving parts and they are compact in size which makes them reliable over a long period of time .The TECs are also used to convert waste heat from the industry into electricity. However, the relatively low conversion efficiency of thermoelectric cells (3-5%) have greatly limited its potential as power generator and resulted in higher operational cost [2]. Besides exploring the material science of the thermoelectric cells, optimizing the heating and cooling rate can be a design consideration to improve the overall system. The efficiency for TECs is given by dimensionless figure of merit, ZT of the TEC material. The equation to calculate figure of merit is given as follow:

$$ZT = \frac{\alpha^2 \sigma T}{k} \tag{1}$$

where α is the Seebeck coefficient, σ is the electrical conductivity, ρ is the electrical resistivity, and k is the total thermal conductivity. The figure of merit for Bismuth Telluride based TECs is currently at 1 at 400°C hot side temperature. It is essential to have an effective cooling method at high operating temperature conditions to maintain the temperature difference required for the operation of the TECs. Forced convective cooling methods currently are used when compared to the passive cooling methods which rely on natural convective cooling. Forced convective cooling provides the highest temperature difference for a given heat input when compared to other passive cooling methods. The high temperature of the solar concentrator makes active cooling a preferred method to maintain high temperature difference across the TEC.

Extensive researches on solar concentrators and cooling methods have been conducted to improve the thermoelectricity extraction from the sun. Researchers [3-5] have explored various methods to operate TEC with effective cooling on the cold side of the TEC. A temperature difference is required across the TEC in order to produce electrical power. This is obtained by exposing one side of the TEC to a heat source and the other side is cooled by a heat sink. The conversion efficiency of the TEC's shows strong linear dependence on the temperature difference. Therefore, high heat flux loads enables the TECs to operate at higher electrical output. Various researchers have utilised parabolic trough and compound parabolic concentrators to increase the intensity of the heat and thus temperature on the hot side of the TEC [6-10].

TEC can directly convert thermal energy into direct current (DC) electricity. These TECs have been used extensively worldwide for power generation for more than 40 years now. Power generation based on the TEC system offers great advantage compared to photovoltaic (PV) system, in terms of cost. The cost for TEC system is as low as 1500 \$/kW, compared to cost of PV system at 6000 \$/kW [11]. This makes TEC based system a cheaper alternative compared to PV systems for power generation. Besides that, PV load factors are also low and lowest in winter, when the demand is highest [11]. This makes the PV system operate at low performance. The concentrator application used for the TEC systems enables high temperature concentration of solar energy, even during winter and this available high temperature solar energy can be easily converted to DC electricity using TECs.

Concentrated solar rays can reach temperatures as high as 300°C, in some cases around 400°C [12]. The high temperature will not be feasible for power generation using PV system. TECs on other hand can operate at temperatures up to 400°C [13]. This makes them a good candidate for power generation from concentrated solar energy application. If the source of energy is cheap or free, like the solar energy and waste heat, then the efficiency of the TEC system is not an overriding consideration [14]. Instead, this increases the commercial competitiveness of TEC system for electrical power generation, compared to other currently available systems like the PV systems. Increasing the efficiency of a system like diesel cycle and gas turbine cogeneration is possible nowadays by using TEC system. Traditionally, the waste heat from the above systems was exhausted as a waste heat, but this can now be converted into electricity using TECs [15]. The overall efficiency of the system can be increased significantly by tapping the waste heat and converting it into electricity using TECs. TECs allow a symbiotic relationship between the waste heats generated by the machineries and converting it into electricity. This help increase the overall performance of the machineries where the waste heat is converted into electricity and this energy is redirected back into it to increase its overall efficiency.

A quarter of the population on this planet are still living without electricity. Generating power from concentrated solar energy using TEC system promises a good future to these people. In remote areas, where the electricity grid is not available and the sun shines year round [16], TEC with concentrated solar energy power generation system can be used to provide an alternative to other high cost power generation system. The energy of the sun is abundant and limitless and is more than enough to meet our current energy needs by manyfold. TEC system provides an attractive means of converting solar energy to electricity and can definitely help to connect the remote area to the grid. The relatively simple and low cost with almost zero maintenance promises TEC system to be a good source of power generation system from solar energy for remote areas.

In this paper, preliminary indoor laboratory experiments were conducted to investigate the potential electrical power generation from the TEC coupled with the Fresnel lens concentrator. These experiments were carried out indoors and under simulated solar concentrations. The heat source from the Fresnel lens was replaced by cartridge heaters to simulate the concentrated heat source from the sun. The objective of this work is to optimize the water-cooled based CTEG power system by understanding the influence and effects of water flow rates, different heating power and compressive stresses on the TEC device. In order to obtain a good contact between the surfaces, the hot and cold side of the TEC needs to be compressed. This will reduce thermal contact resistance between the TEC, the cartridge heater block and the cooling block. Additionally, the coupling of such heating and cooling elements to the thermoelectric cells have certain effects on the electric output where over-compressive stress may not be beneficial to the power output.

Concentrating thermoelectric generator (CTEG) system

TEC is made up of two dissimilar materials (P-type and N-type semiconductors) which are electrically connected in series and thermally in parallel as shown in Figure 1. An acrylic based Fresnel lens is used as the solar concentrator for providing high concentrated solar flux onto the heat collector which is thermally coupled with the hot side of the TEC. In order to provide a temperature difference across the TEC for thermoelectricity generation, a water-cooled cold plate was attached on the cold side of the TEC for dissipating the accumulated heat as shown in Figure 1.

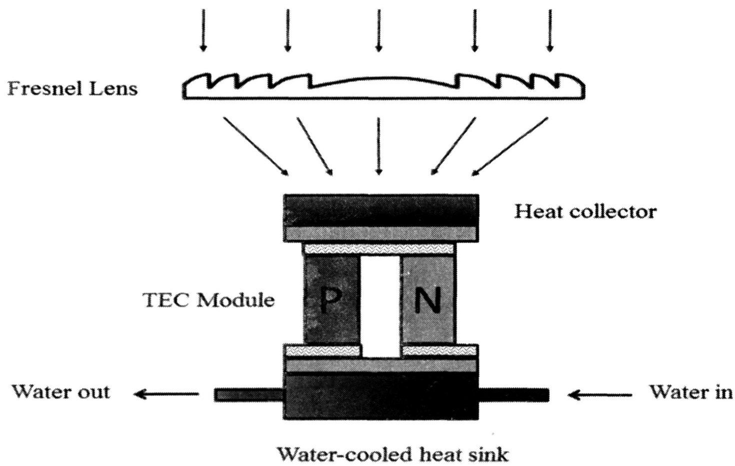

Figure 1: Schematic diagram of a thermoelectric cell (TEC) under solar concentration using a Fresnel lens

The TEC used in this experiment is made up of bismuth and telluride (BiTe) type of semiconductor. Bismuth Telluride cells are widely used as thermoelectric coolers (Peltier effect) and low operating temperature (< 200°C) power generating units (Seebeck effect). It has relatively high Seebeck coefficient (~ 190 μV/K) and high figure of merit (~ 2 x 10^{-3} K^{-1}), with individual dimensions of 40 mm (length) x 40 mm (width) x 3.9 mm (height) and 127 thermo elements per cell. Figure 2 shows the picture of one such thermo electric cell with wiring.

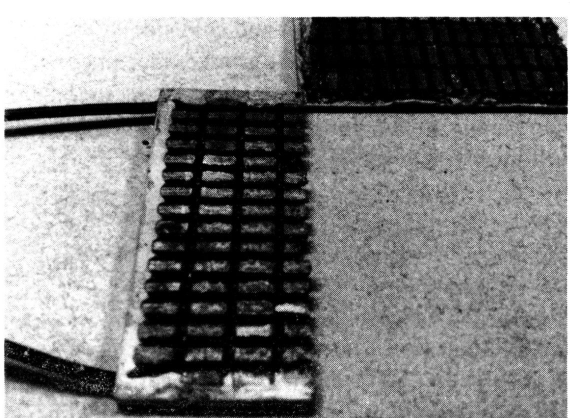

Figure 2: Bi-sectional views of a Peltier type thermoelectric cell (TEC)

Heat is supplied on one side of TEC while the other end is maintained at a lower temperature via a heat sink. Due to the temperature difference, current will flow through an external load resistance. The output power depends on the temperature difference, the properties of the semiconductor materials and the external load resistance. Each thermoelectric element is insulated, both electrically and thermally, from its surroundings, except at the junction to hot/ cold reservoir contacts.

Experimental set up

In order to determine the optimal design and settings for a water-based cooling CTEG system, various heating and cooling conditions were conducted indoor on a single TEC. The objective is to explore the thermoelectric output power performance under different parameters such as cooling water flow rates, solar concentrations and compressive stresses at TEC contact interface. This analysis is important knowledge during the preliminary stage of development of a water-cooled CTEG system to achieve optimal design settings and reduce operational cost. In addition, Peltier cell is used as TEC as it is relatively inexpensive compared to Seebeck cell which is specially designed for high temperature thermoelectric generation. Peltier cell is widely used as thermoelectric refrigeration such as portable coolers. Providing a temperature gradient across this cell leads to the Seebeck effect where the output power is similar to Seebeck cell at low temperature environment (<150°C). It is also noted that the Peltier cell used in this analysis has a maximum operating temperature of 150°C.

The test set-up is shown in Figure 3a and the schematic diagram of the setup in Figure 3b. One side of the TEC is heated using a heat simulator made of copper block inserted with cartridge heater. The cold side is cooled using liquid cooled heat sink where water is pumped into the cooling block in which is installed with internal fins to provide a greater heat transfer performance. The temperatures were measured on the hot and cold side of the TEC using T-type thermocouples that where fixed inside the grooves machined on the heater block and liquid heat sink. In order to avoid any heat losses to the ambient, the test sample was completely shielded using polystyrene insulation. The formula to calculate the efficiency, η of the TEC is given below:

$$\begin{aligned}\eta &= P_{out} / P_{in} \\ &= [\dot{m} \times c_p \times (T_{out} - T_{in}) + P_{TEG}] / (VI)_{heater} \qquad (2)\end{aligned}$$

The input power of the heater is given by the voltage (V) and the current (I) applied for the different set of heating. The power output is calculated from the mass flow rate of cooling water ($\dot{m}$) with specific heat capacity (c_p) and the temperature difference between the cold water at inlet (T_{in}) and cold water at outlet (T_{out}). The formula to calculate Carnot efficiency, η_c is given by the formula below:

$$\eta_c = \frac{T_h - T_c}{T_h} \tag{3}$$

where T_h is the hot surface absolute temperature and T_c is the cold surface absolute temperature of the TEC.

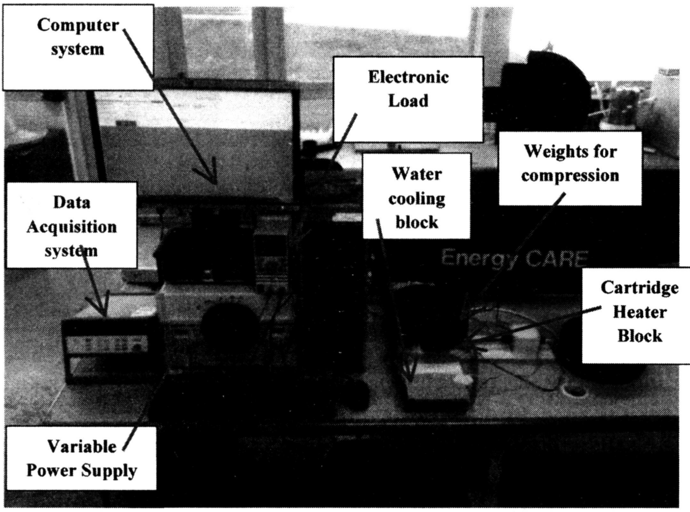

Figure 3a: Experimental facility showing details of set-up used to test the performance of TEC

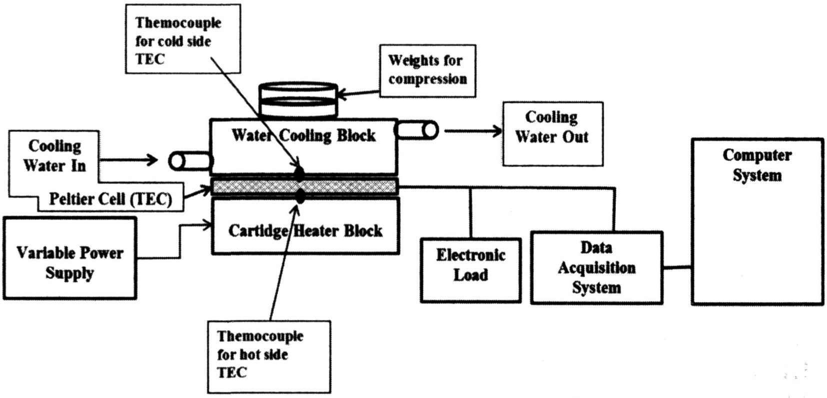

Figure 3b: Schematics of experimental set-up used to test the performance of TEC

In order to understand the thermal effect of compressive forces between the TEC faces and heat exchange surfaces, interfacial pressure was applied using weights (in kg) of 10,15..etc as shown in Figure 3a. Data from the thermocouples were recorded on the computer using Agilent 349070A data logger unit. The maximum power output was determined by a digital rheostat (model: BK Precision 8540, 150W DC). Figure 4 shows the heater and the cooling block and the set-up when weights were used for compression in order to reduce thermal contact resistance for the experimental set-up.

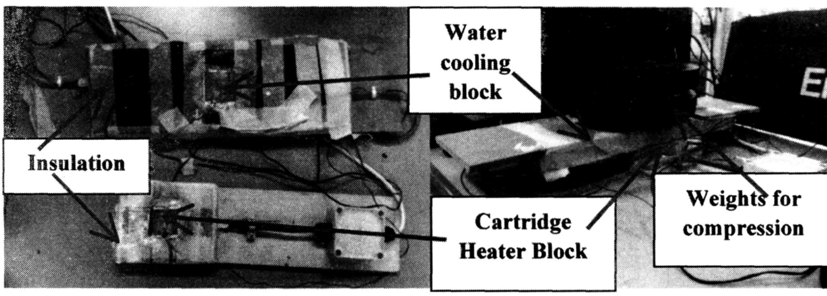

Figure 4: Water-cooling heat sink (Top-left), electric heater (Bottom-left) and compression test using weights (Right)

Results and Discussion

The first test objective is to determine the cooling water flow rate on the cold side required for steady state performance of the experimental set-up. The cooling water used for the setup is supplied by the town council water supply. There will be no need for external pumping source for the pumping of the water for the cooling of the TEC on the cold side. The cooling water flow can also be supplied by a gravity feed system or an external pump powered by the solar energy. This is important to minimise or eliminate the parasitic load to the entire system. Three different flow rates were used to obtain the performance of the cell. The external power supplied to the hot side of the TEC was chosen at 20 watts for the above. Figure 5 shows that by increasing water flow rate on the cold side of the TEC, the power output from the TEC increases. The results for 11.11ml/s and 25.00 ml/s are identical as seen in Figure 5.This is because the cooling rate for both the flow rates provides the same effect. It can be concluded that the optimum cooling rate required for the cold side is 11.11ml/s, as the higher flow rates will not increase the power output of the TEC. The subsequent experiments were conducted with this flow rate.

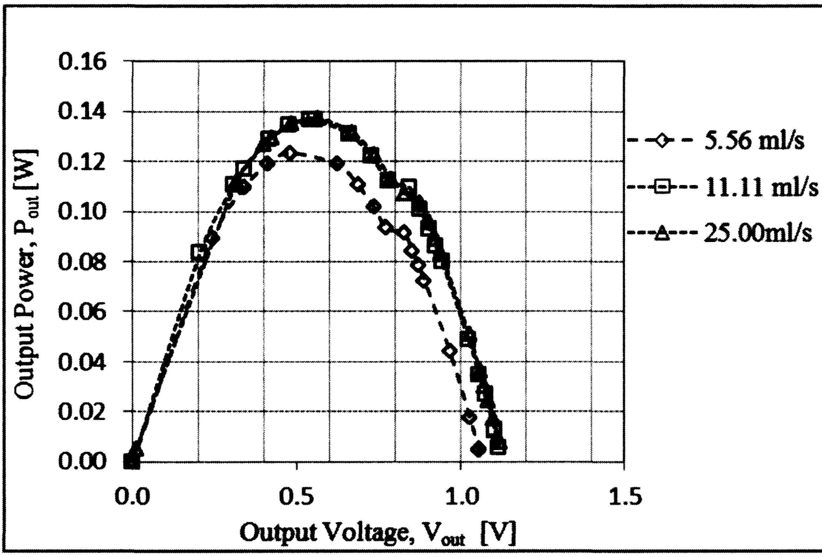

Figure 5: Effect of Flow Rate to Output Power

This results in higher heat transfer rate. Few set of weights were used to apply the compression needed for the experimental setup. Weights from 10 kg to 40 kg, with an increase of 5 kg between them were applied to the experimental set up. The result of this analysis is shown in Figure 6. From Figure 6, it is evident that the output power increases with the increase in the weights applied. The maximum power occurred at 30 kg. From Figure 6, the difference between 25 kg weight and 30 kg weight is negligibly small. From the results, it was shown that the 30 kg weights applied provides the maximum compression for maximum power output. The experiment is then continued with this weight for all other external power supply to the hot side of the TEC.

At 40 kg compression weight, significant drop in power was observed. This is due to the cracks in the TEC developed because of high compression. Based on the results obtained, the maximum loading stress for the TEC is at 245.25 kPa and it should not be exceeded in order to avoid damage to the TEC. The loading stress was obtained by dividing the weight (Newton) applied to the set-up with the surface area of TEC.

Once the flow rate and the required compression was established, the output power supply was varied to obtain the I/V (output current versus the output voltage) characteristic of the TEC. Figure 7 shows the output current, I_{out} [A], versus the output voltage, V_{out} [V] for several temperature gradients, $\Delta T = T_H - T_C$ [°C]. The output current increases with increase in

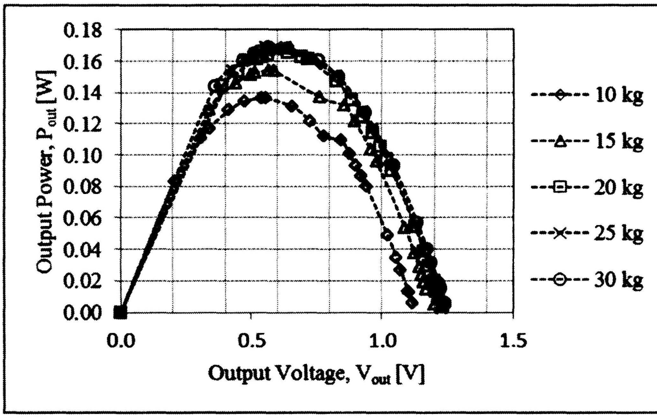

Figure 6: Output power with different compression weights

external power supply, P_{in}. External power supply, P_{in} [W] of 20 to 160 Watts was applied to the hot side of the TEC. The respective cold side temperature was recorded at 29.03°C, 33.83°C, 38.76°C, 43.70°C, 49.86°C, 54.14°C, 59.15°C, and 64.27°C. The cold side temperature increases with the power input from 20W to 160W because of the higher heat transfer from the hot side of the TEC

From Figure 7, a high linearity can be observed in all I/V plots with the same slope. This means that the internal resistance of the TEC is constant with

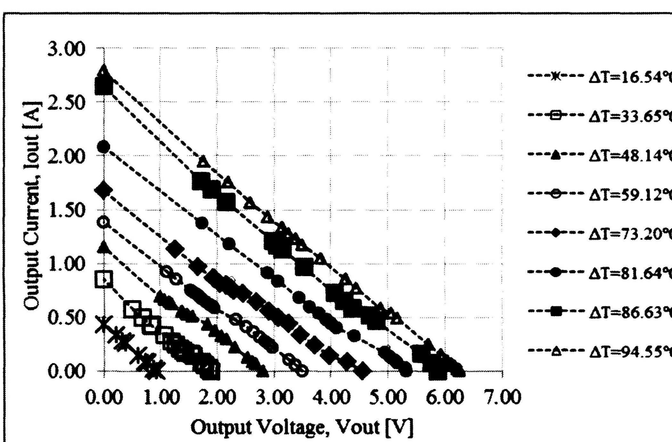

Figure 7: The output current versus the output voltage for several temperature differences across the TEC

the test temperatures on the hot side and the load operations. This will result in clear existence in clusters of internal resistances, as shown in Figure 8. In order to calculate the statistical behaviour of these clusters, their medium ($\mu_i \in$ 2.36, 2.22, 2.42, 2.43, 2.52, 2.45, 2.33, 2.43 Ω) and standard deviation ($\sigma_i \in$ 0.13, 0.21, 0.37, 0.23, 0.38, 0.21, 0.25, 0.49 Ω) were calculated and shown in Figure 9.

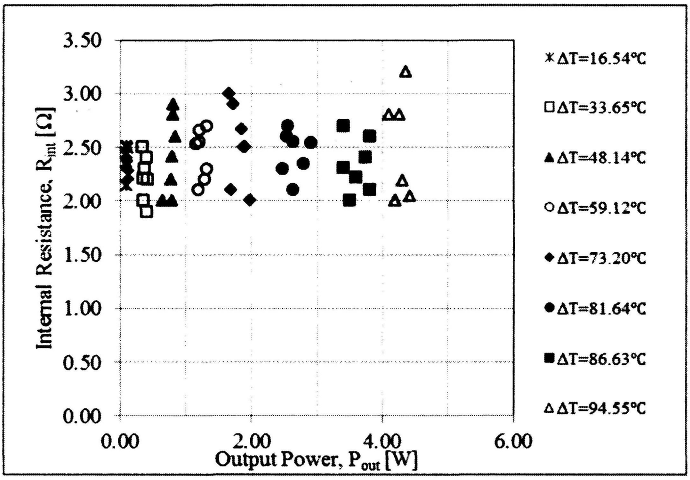

Figure 8: The internal resistance of thermoelectric converter, R_{int} [Ω] versus the output power, P_{out} [W], for several temperatures differences across TEC

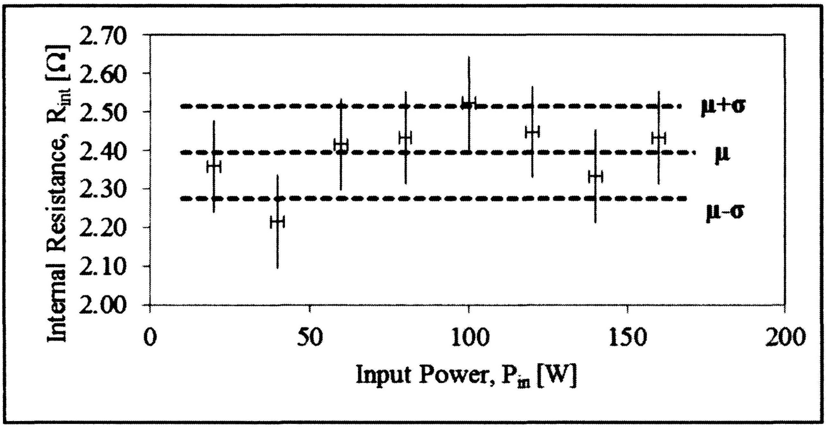

Figure 9: The medium and standard deviation values of the internal resistance of the TEC, R_{int}, [Ω], versus the output power, P_{out} [W]

The length of the intervals (the standard deviation) around the centre values of the clusters (their medium) can be considered to have the same order magnitude. This indicates repetition of certain pattern on the behaviour of TEC. The possible explanation for this discrepancy is the variability of the measuring conditions due to the high test temperature involved in the characterisation process (e.g., calorimetric leaks and convection around hot plate). The central line of the three horizontal line in figure 9 represents the medium of the mediums (e.g., $\mu = [\mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5 + \mu_6 + \mu_7 + \mu_8]/ 8 = 2.40\Omega$), while the equal distances between the central line (μ) to the top and the bottom lines is the standard deviations ($\sigma = \sigma_{1,} \sigma_{2,} \sigma_{3,} \sigma_{4,} \sigma_{5,} \sigma_{6,} \sigma_{7,} \sigma_{8,} \approx 0.12\Omega$). These last two lines are located on $\mu + \sigma$ and $\mu - \sigma$, respectively. From this analysis, it is possible to conclude that the internal resistance of the analysed TEC is equal to $R_0 = 2.40\Omega$, with a tolerance equal to $\Delta R_{int} = 0.12\Omega$, thus $R_{int} = R_0 \pm \Delta R_{int} = 2.40 \pm 0.12\Omega$.

It is also observed from figure 10 that the output power increases with the increase in input power. This is due to the rise in output voltage, V_{out} [V] as the temperature gradient, $\Delta T = T_H - T_C$ [°C] increases. This will then result in an increase in the output current, I_{out} [A]. The dissipated power corresponds to the external load resistance applied, R_L [Ω]. Maximum power occurs when the external load resistance R_L [Ω] is equal to the internal resistance, Rint [Ω] of the TEC, e.g, $P_{out} = R_L I_{out}$ [W]. Figure 10 shows the output power P_{out} [W] versus the output voltage V_{out} [V]. The output power increases P_{out} [W] with the increase in temperature difference, $\Delta T = T_H - T_C$ [°C] or external power applied P_{in} [W] to the hot side of the TEC. Figure 11 is an alternative set of plots, but for the output power P_{out} [W] versus the output current I_{out} [A].

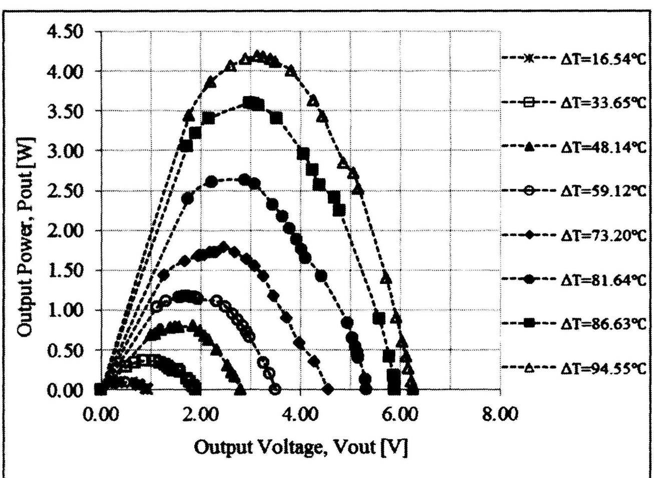

Figure 10: Output power P_{out} [W] versus the output voltage V_{out} [V]

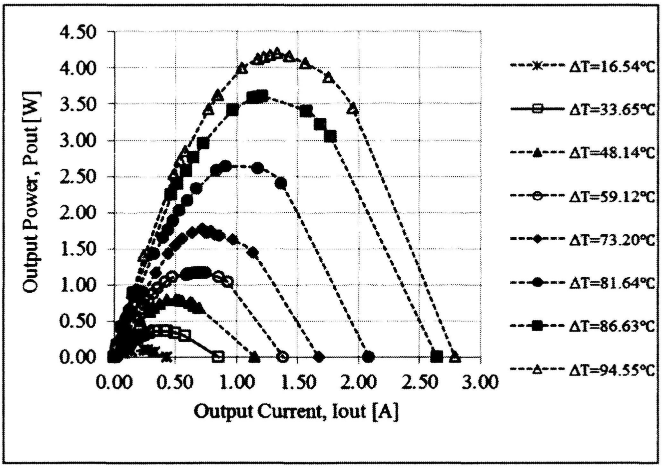

Figure 11: Output power, P_{out} [W] versus the output current, I_{out} [A]

Figure 12 shows the plot for open-circuit voltage, V_{open} [V] versus the temperature difference, $\Delta T = T_H - T_C$ [°C] across the TEC. The open-circuit voltage, V_{open} [V] was measured at the output of the TEC without any external resistance load, R_L [Ω] applied to the TEC. An open- voltage function was obtained by curve-fitting the plot for Figure 12, as shown below.

$$V_{open} = 0.0641\, \Delta T \text{ [V]} \tag{4}$$

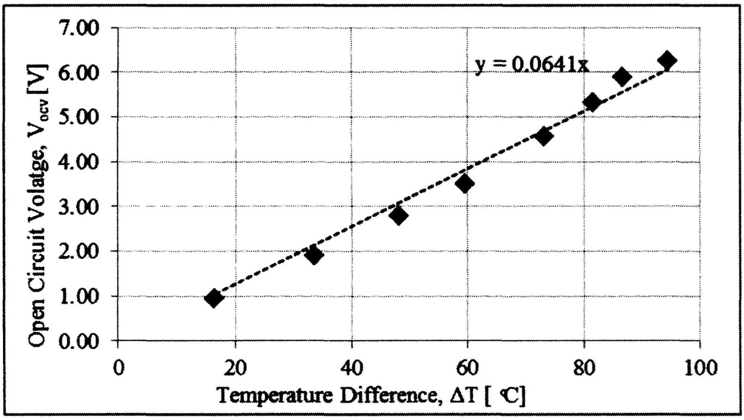

Figure 12: Open Circuit Voltage, V_{open} [V] versus the temperature difference, $\Delta T = T_H - T_C$ [°C] across the TEC

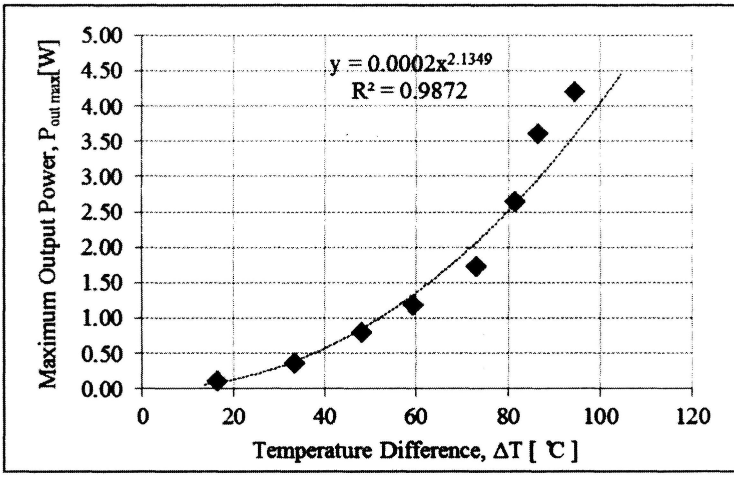

Figure 13: Maximum output power, $P_{out\ max}$ [W] versus the temperature difference, $\Delta T = T_H - T_C$ [°C] across the TEC

Figure 13 shows the plot for maximum output power, $P_{out\ max}$ [W] versus the temperature difference, $\Delta T = T_H - T_C$ [°C] across the TEC. The maximum output power increases with the increase in the temperature difference across TEC. A line was fitted to the plot to obtain the relationship between the two parameters than can be useful to predict the power output from the TEC based on the temperature difference, as shown below. This relationship is valid for TEC operating with a max temperature difference of 100°C.

$$P_{out\ max} = 0.0002*(\Delta T^{2.1349})\ [W] \tag{5}$$

The indoor test provides useful data for the outdoor experiment using the Fresnel lens for the heat source. The optimum cooling flow rate and the compressive force from the experiment will be useful for design of the final outdoor test rig with optimal design setting with minimum cost. The Peltier cell used in the experiment can be used with concentrated solar radiation for power generation application under 150°C hot side temperature.

Conclusions

A series of parametric studies were conducted on a single TEC to investigate the effects on performance during the development of a water-cooled CTEG system. These experiments were carried out indoors and under simulated solar concentrations. The experiment results have shown that compressive stresses on TEC plays important roles in CTEG system or any waste heat recovery systems which some designers may ignore. The TEC was able to produce maximum power of 4.19W at 94.55°C and 2.62% conversion efficiency was produced from a single thermo electric generator. In summary, with careful design considerations in waste heat recovery system using water-cooling system, the operation cost can be reduced with higher thermoelectric power output and lower maintenance cost. This study also revealed that for a specific design, a water-cooled cold plate has a maximum cooling capacity which allows designers to take into account to avoid high pressure head and result in unnecessary maintenance arising from water leakages.

References

[1] D.M. Rowe. (1995). CRC Handbook of Thermoelectrics, (CRC Press, Florida, USA.

[2] Wei-Hsin Chen, Chen-Yeh Liao, Chen-I Hung and Wei-Lun Huang. (2012). "Experimental study on thermoelectric modules for power generation at various operating conditions" Journal of Energy, Vol. 45, pp. 874-881.

[3] X. Niu, J. Yu and S. Wang. (2009). "Experimental study on low-temperature waste heat thermoelectric generator", Journal of Power Sources, Vol. 188, pp. 621-626.

[4] S. Tundee, R. Singh, P. Terdtoon and A. Akbarzadeh. (2008). "Power Generation from Solar Pond Using Combined Thermosyphon and Thermo Electric Modules", Proceedings of the 7th International Conference on Sustainable Energy Technologies-SET2008,Seoul, Korea, 24-27 August.

[5] A. Rezania and L.A. Rosendahl. (2012). "Thermal Effect of a Thermoelectric Generator on Parallel Microchannel Heat Sink." Journal of Energy, Vol. 37, pp. 220-227.

[6] S. Maneewana and B. Zeghmatib. (2007). "Comparison Power Generation by Using Thermoelectric Modules between Cooling Module and Power Module for Low Temperature Application", International Conference on Thermoelectrics, pp. 290-293.

[7] S. Maneewan, J. Khedari, B. Zeghmati, J. Hirunlabh and J. Eakburanawat. (2003). "Experimental Investigation on Generated Power of Thermoelectric Roof Solar Collector", 22nd International Conference on Thermoelectrics, pp. 574-577.

[8] G.F. Rinalde, L.E. Juanico, E. Taglialavore, S. Gortari and M.G. Molina. (2010). "Development of Thermoelectric Generators for Electrification of Isolated Rural Homes" International Journal of Hydrogen Energy. Vol 35, pp. 5818-5822.

[9] Y Qi Zhang, Amen Agbossou, Zhihua Feng and Mathieu Cosnier (2010). "Solar micro-energy harvesting based on thermoelectric and latent heat effects. Part II: Experimental analysis". Journal of Sensors and Actuators, Vol. 163, pp. 284-290.

[10] S. A. Omer and D. G. Infield. (2000). "Design and thermal analysis of a two stage solar concentrator for combined heat and thermoelectric power generation", Energy Conversion & Management, Vol. 41, pp. 737-756.

[11] R.K. Aggarwal and S. Markanda. (2012). "A review on thermocouple for power generation", Int. Journal of Applied Sciences and Engineering Research, Vol.1, No. 2, pp. 98-105.

[12] S.A. Omer and D.G. Infield. (1998). "Design optimization of thermoelectric devices for solar power generation", Solar Energy Materials and Solar Cells, Vol. 53, pp. 67-82.

[13] S.B. Riffat and Xiaoli Ma. (2003). "Thermoelectrics: a review of present and potential applications". Applied Thermal Engineering, Vol. 23, pp. 913-935.

[14] D.M. Rowe. (1999). "Thermoelectrics, an environmentally-friendly source of electrical power", Renewable Energy, Vol.16, pp. 1251-1256.

[15] Chinh Wu. (1995). "Analysis of waste-heat thermoelectric power generators", Applied Thermal Engineering, Vol.16, pp. 63-69.

[16] N.M. Khattab and E.T. El Shenawy. (2006). "Optimal operation of thermoelectric cooler driven by solar thermoelectric generator", Energy Conversion and Management, Vol. 47, pp. 407-426.

JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Aims & Scope

Journal of Mechanical Engineering (formerly known as Journal of Faculty of Mechanical Engineering) or JMechE, is an international journal which provides a forum for researchers and academicians worldwide to publish the research findings and the educational methods they are engaged in. This Journal acts as a vital link for the mechanical engineering community for rapid dissemination of their academic pursuits.

Contributions are invited from various disciplines that are allied to mechanical engineering. The contributions should be based on original research works. All papers submitted to JMechE are subjected to a reviewing process through a worldwide network of specialized and competent referees. To be considered for publication, each paper should have at least two positive referee's assessments.

General Instructions

Manuscripts intended for publication in JMechE should be written in camera ready form with production-quality figures and done electronically in Microsoft Word 2000 (or above) and submitted online to jmeche.int@gmail.com. Manuscripts should follow the JMechE template.

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Paper Title in Arial 18-point, Bold and Centered

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ABSTRACT

The first section of the manuscript should be an abstract, where the aims, scope and conclusions of the papers are shortly outlined, normally between 200 and 300 words. TNR-10 italic

Keywords: *maximum 5 keywords.*

Title of First Section (Arial 11 Bold)

Leave one blank line between the heading and the first line of the text. No indent on the first para after the title; 10 mm indent for the subsequent para. At the end of the section, leave two blank lines before the next section heading. The text should be right and left justified. The recommended font is Times New Roman, 10 points. In 152 mm x 277 mm paper size, the margins are: left and upper: 22 mm each; right: 20 mm, lower: 25 mm.

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Tables and illustrations should be numbered with arabic numbers. Tables and illustrations should be centred with illustration numbers written one blank line, centered, after the relevant illustration. Table number written one line, centered, before the relevant table. Leave two blank lines before the table or illustration. Beware that the proceedings will be printed in black and white. Make sure that the interpretation of graphs does not depend on colour. In the text, tables and figures should be referred to as Figure 1 and Table 1.

The International System of Units (SI) is to be used; other units can be used only after SI indications, and should be added in parenthesis.

Equations should be typed and all symbols should be explained within the manuscript. An equation should be proceeded and followed by one blank line, and should be referred to, in the text, in the form Equation (1).

$$y = A + Bx + Cx^2 \tag{1}$$

Last point: the references. In the text, the references should be a number within square brackets, e.g. [3], or [4]–[6] or [2, 3]. The references should be listed in numerical order at the end of the paper.

Journal references should include all the surnames of authors and their initials, year of publication in parenthesis, full paper title within quotes, full or abbreviated title of the journal, volume number, issue number and pages.

Examples below show the format for references including books and proceedings

Examples of references:

[1] M. K. Ghosh and A. Nagraj, "Turbulence flow in bearings," Proceedings of the Institution of Mechanical Engineers 218 (1), 61-4 (2004).

[2] H. Coelho and L. M. Pereira, "Automated reasoning in geometry theorem proving with Prolog," J. Automated Reasoning 2 (3), 329-390 (1986).

[3] P. N. Rao, Manufacturing Technology Foundry, Forming and Welding, 2nd ed. (McGraw Hill, Singapore, 2000), pp. 53-68.

[4] Hutchinson, F. David and M. Ahmed, U.S. Patent No. 6,912, 127 (28 June 2005).