Development of Waste Heat as Alternative Energy

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Abstract — Renewable energy is generally defined as energy that is collected from resources which are naturally replenished on a human timescale either from natural or environment and it is also known as the alternative energy. This paper intends to explore the opportunities to produce electricity from waste heat from our surrounding equipment especially household appliances as one of the renewable energy sources by using thermoelectric generator module. By using ‘Seebeck effect’, electrical energy could be generated with the difference of temperature between surfaces. This study reveals the ability of waste heat to generate electricity by using candle, cooking stove, Bunsen burner, BBQ grill placement and kettle as a source of heat for activate at least a small electronic device. The main findings on this project are that with higher temperature differences, the higher voltage is produced.

Keywords – Household appliance, thermoelectric generator (TEG), DC-DC booster.

I. INTRODUCTION

Tenth Malaysia Plan[1] shows the Malaysian Government support on implementing renewable energy with several new initiatives by contributing 5.5% to Malaysian total electricity generation mix with target of 985 MW by 2015 are anchored upon the Action Plan undertaken and Renewable Energy Policies.

According to C S Tan et al. [2], there have three objectives of Malaysia energy development which currently guided by the National Energy Policy which is supply objective that to ensure energy supply adequate, secure and cost-effective to supply while utilization objective is to encourage efficient utilization of energy and discourage wasteful and non-productive patterns of energy consumption, and lastly, the environmental objective is to ensure the environmental protection and the factors pertaining are not neglected when the production and utilization of energy.

The problem statement of this project are glance toward the most innovations were focused on large amount of voltage without realizing the essential requirements such as the smart phone, lamp and small fan only requires low voltage to function. When mentioned all those devices with low voltage, nowadays already have power back up like power bank but to remember it still using electricity to charge.

Recalled on the floods tragedy on December 2014, the worst mud floods hit in several states especially in the east coast of Malaysia like Kelantan, Terengganu and Pahang until causing electricity outage and almost severed communication links. During this time, most of flood victims hope the volunteers brings the extra back up power whether generator or power bank to ensure at least they could still activate their phone and stay could communicate with others until the reporter and NGO’s lists one of the needs of flood victims are power bank or batteries besides food and clothing.

There are three main objectives associated with this project, which is:

i. To study the appropriate renewable energy sources.

ii. To carried out experimentally of the electricity development from waste heat source.

iii. To analyzed and evaluated the output range produced and the ability of waste heat source whether it capable to supply a sufficient voltage and activate at least a small electronic devices.

This project are comes out with the special significant that could produce electricity everywhere and anywhere as long as heat available. At the same time, this project becomes one of the alternative ways to develop electricity during emergency or needed and makes surrounding environment to be useful. The four pillar green technology that introduced by this project as Table 1 below.
TABLE 1: GREEN PILLAR TECHNOLOGY

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Attain energy independence and encourage efficient utilization.</td>
</tr>
<tr>
<td>Environment</td>
<td>The impacts on the environment are minimized and conserved.</td>
</tr>
<tr>
<td>Economy</td>
<td>The use of technology will enhance the national economic development.</td>
</tr>
<tr>
<td>Social</td>
<td>Improve quality of life</td>
</tr>
</tbody>
</table>

The scope of this project are ensure the successful of produced electricity from waste heat from appliance by using Seebeck effect for at least to activate the electronic device such as LED or small fan. The source of waste heat are comes from candle, stove, Bunsen burner and barbecue (BBQ) grill placement.

The need of renewable energy in Malaysia due to[3]:

i. High electricity demands. This proved by increasing 5% to 8% in electricity demand annually and need additional 10GW by 2020.

ii. GHG emission reduction targets that need 40% reduction of emission in 2005 by 2020.

iii. Ecological issues on large hydropower. This is due to the lack of large hydro potential in peninsular and the ecological resistance of Borneo region.

iv. Effects nuclear options due to Fukushima nuclear incidents on 11 March 2011.

v. Coal reliability issues that have low domestic supply and the economic growth in coal export countries may lead to coal supply shortage.

vi. Viability of gas based power. The era the availability of cheap natural gas will come to the end. This is due to decline in domestic gas supply and demand increase from competing sectors.

According to M. Hasanuzzaman et al. [4], significant improvement to an engine performance, efficiency, reliability, and design flexibility can be achieved by converting the waste heat into electricity. Benefits of waste heat recovery can be broadly classified in two categories[5]:

i. Direct Benefits:
Recovery of waste heat has a direct effect on the efficiency of the process. This reflected by reduction in the utility consumption & costs, and process cost.

ii. Indirect Benefits:
   a. Reduction in global and environmental impacts. It serves dual purpose such recovers heat and reduces the environmental pollution levels.
   b. Reduction in equipment sizes. It reduced the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipment such as stacks, ducts, burners, etc.
   c. Reduction in auxiliary energy consumption by reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.

TEG is solid-state device, which means that have no moving parts during their operations. Together with features is it produce no noise and involve no harmful agents. The advantages of TEGs over other technologies[6]:

i. Extremely reliable because of no mechanical moving parts thus considerably less maintenance.

ii. TEG have very small size and weightless.

iii. The capacity to operating is at elevated temperatures.

iv. The source for the power generation is heat source, so in daytime and night, it still possible to operate.

v. Mostly used to converting the waste heat to electricity so it considered as a Green Technology.

vi. Overall efficiency of the system will increased from 4% to 7%.

vii. Become the simple alternative power sources compared to exciting conventional power system it required less space and cost.

II. METHODOLOGY

Figure 1 and Figure 2 shows the overall steps of project and analyze the findings of each experiment following the sequential of flow chart.

Figure 1: Flow Chart of Project Works
The basic equipment and materials used for this project are as Figure 3 but excluded of DC-DC booster circuit component. All the listed above should have before conducting the experiment. Furthermore, the equipment needed is cooking stove and kettle.

A. Procedure Of TEC Functional Testing

1. Experimental equipment and materials set up.
2. Determine the ambient temperature (T_a).
3. Connect the multimeter to TEC module (positive at red wire and negative to black wire).
4. Put TEC module on top of heat source (e.g. candle).
5. Verify side of module whether hot or cold side by the polarity shown on the multimeter. If multimeter show the negative value, flip the TEC module. Then, mark the hot side of module.
6. Record the output voltage after one (1) minute.
8. Repeat step 3 until step 7 for each module being tested.

B. Electricity Development Design

The full block diagram of project design as Figure 4 was used to express the configuration of equipment from waste heat source until load.

C. DC-DC Booster Circuit Design

The circuit diagram as Figure 5 was used as DC-DC booster circuit that using IC of MAX756 as driver to boost up small input voltage starting from 0.7V up to 5V.


**D. Manufacture Data**

For TEG theory calculation,

\[ V_o = (SM \times DT) = I \times (RM + RL) \]  

* \( V_o \) is the generator's output  
* \( I \) is output current  
* \( SM \) is the module's average Seebeck coefficient  
* \( DT \) is the temperature difference across the couple  
* \( RM \) is the module's average resistance  
* \( RL \) is the load resistance

Assumption:  
- \( SM = 0.05818 \text{ V/K} \)  
- \( DT = \text{From 0 to 150} \)  
- \( RM = 0.8 / 1.9 / 2 \text{ ohms} \)  
- \( RL = 1.7 / 1.8 / 2.02 \text{ ohms} \)

For DC-DC booster circuit, the MAX756 manufacture data was used as reference to compare the performance of experimental circuit. This data can be used because the circuit diagram provided from the datasheet was used. Therefore, the data chosen to be compared is a graph of maximum output current versus input voltage.

**III. RESULTS AND DISCUSSION**

**A. TEC’s Ability**

On this part, each TEC were tested to choose the best TEC for each appliance. The entire test was taken during ambient temperature, \( T_a = 30.4 \text{ ºC} \) and heat source from candle (temperature maximum of candle is 120ºC).

**TABLE 2: OUTPUT PRODUCED FROM TEC**

<table>
<thead>
<tr>
<th>Types</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC1-12706</td>
<td>0.80–1.28</td>
<td>80</td>
<td>0.0720</td>
</tr>
<tr>
<td>TEC1-12708</td>
<td>0.60–0.85</td>
<td>70</td>
<td>0.0520</td>
</tr>
<tr>
<td>TEC1-12715</td>
<td>0.30–0.40</td>
<td>15</td>
<td>0.0045</td>
</tr>
</tbody>
</table>

The results of functional testing of TEC were tabulated in Table 2 this gives an idea to choose the best TEC for each appliance. The TEC that have good performance was TEC1-12706 but need to remember TEC had temperature characteristics need to consider. Due to this testing were conducted in low temperature, so the performance of TEC1-12715 have low performance. Although TEC1-12715 output are low but it have special characteristics which is it have high performance in high temperature compared to TEC1-12706 and TEC1-12708 that have similarities on operating temperature difference, \( \Delta T \).

**B. Types Of Design**

Design is necessary to emphasize each design could give different results. Figure 6 shows the configuration of design used in this project and shows the results from different sources of heat to determine the best design based on output produced. Method of cooling system also give an impact to output produced due to the cooling system are tightly related to the main factor of increasing temperature different.

**TABLE 3: RESULTS WITH DIFFERENT LAMINATION**

<table>
<thead>
<tr>
<th>Design</th>
<th>( \Delta T )</th>
<th>( V )</th>
<th>( mA )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Laminating</td>
<td>17.9</td>
<td>0.85–1.03</td>
<td>124.3</td>
</tr>
<tr>
<td>Steel laminating</td>
<td>22.5</td>
<td>0.70–1.20</td>
<td>120.0</td>
</tr>
<tr>
<td>Copper laminating</td>
<td>24.6</td>
<td>1.10–1.25</td>
<td>132.3</td>
</tr>
</tbody>
</table>

From Table 3, it shows that copper laminating have the higher output produced compared the others. The results with laminating have much better results but since the temperature were not constant and makes the output always changes, therefore the best designed chosen was without laminating design. This is due to the TEC closed to heat source and have a constant heat with a good cooling system. Even the design chosen have lower output value but it have a constant temperature value in certain time thus avoid rapidly changes output.

**C. Waste Heat Development**

Table 4 and Figure 8 shows the testing temperature and generated voltage from different testing appliance that have a potential to develop electricity even could only produce a very low power respectively.

**TABLE 4: TESTING TEMPERATURE**

<table>
<thead>
<tr>
<th>Appliance</th>
<th>( T_a ) (°C)</th>
<th>( T_c ) (°C)</th>
<th>( T_h ) (°C)</th>
<th>( \Delta T )</th>
<th>TEG Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candle</td>
<td>28.2</td>
<td>86.5</td>
<td>104.2</td>
<td>17.9</td>
<td>12706</td>
</tr>
<tr>
<td>Bunsen burner</td>
<td>28.2</td>
<td>32.4</td>
<td>58.4</td>
<td>26.0</td>
<td>12706</td>
</tr>
<tr>
<td>BBQ Grill</td>
<td>38.4</td>
<td>156.7</td>
<td>176.4</td>
<td>19.7</td>
<td>12715</td>
</tr>
<tr>
<td>Cooking Stove</td>
<td>35.3</td>
<td>47.0</td>
<td>49.8</td>
<td>2.8</td>
<td>12708</td>
</tr>
<tr>
<td>Kettle</td>
<td>35.3</td>
<td>108.2</td>
<td>126.0</td>
<td>17.8</td>
<td>12708</td>
</tr>
</tbody>
</table>

* \( T_a \) = Ambient temperature  
* \( T_c \) = Cold sides temperature  
* \( T_h \) = Hot sides temperature
These parts to ensure the experimental voltages developed using Seebeck effect from thermoelectric technology are followed. Based on Figure 7, it shows there has slightly difference on voltage produced within calculated and experimental results but it could be accepted due to the calculation are specially created for TEG. Besides that, the difference was comes from several factor such as error during taking results, testing temperature and installation error.

The results of experimental and calculated current by using TEC are shown as Figure 8. A large difference result comes out from this chart due to the assumption made during calculation. TEC are mainly for cooling system but for this project TEC was using as generator due to TEG availability. Therefore, all the assumption made was using the data of TEG of 127 coupling that have the same coupling of TEC.

An experimental result on Table 4 shows that Bunsen burner has higher output results compared to others. This is due to Bunsen burner has good constant heat and has higher temperature where it used gas to burn. Therefore, the temperature difference will increase as well as voltage. Nevertheless, candle has easiest configuration and more safety than others where the maximum temperature of candle only 120ºC and the price is cheaper. The cooking stove has very low voltage. The waste heat are difficult to trap because of the design of cooking stove has non-flat design. Furthermore, BBQ Grill placement also could produce the stable voltage because it has a constant temperature of waste heat but the type of TEC must be correctly chosen. The temperature of operating appliance is more than 300ºC thus the TEC chosen is TEC1-12715 which is having a characteristic that can stand with high temperature. The Ta helps on the results performance, as shows at Table 4. So, from the observation, during the low Ta, the output produced is more than 1V.

D. DC-DC Booster Hardware Design

Figure 9 above shows the DC-DC Booster circuit designed used for this project. The designed was separated from hot area or main area due to protect IC of MAX756 to deal with high temperature that could make it less efficient.

E. DC-DC Booster Circuit Output

These parts discussed on the DC-DC Booster circuit that used to step up the DC voltage to certain values. The useful DC voltage that could activate the small component or devices is from 3V DC. Table 5 below shows the output from DC-DC Booster circuit and the load status either ON or OFF condition. USB LED lamp is used as a load.

<table>
<thead>
<tr>
<th>Input Voltage (V1)</th>
<th>Output Boost Voltage (V2)</th>
<th>Output Current (mA)</th>
<th>Load Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.6</td>
<td>0.9</td>
<td>OFF</td>
</tr>
<tr>
<td>0.7</td>
<td>3.1</td>
<td>35.1</td>
<td>OFF</td>
</tr>
<tr>
<td>1.0</td>
<td>3.5</td>
<td>52.6</td>
<td>ON</td>
</tr>
<tr>
<td>1.5</td>
<td>5.0</td>
<td>101.9</td>
<td>ON</td>
</tr>
</tbody>
</table>

From the observation, the DC-DC booster circuits are experimentally proven when the circuit could function after 0.7V but with small output current, the load still not activated. During experiment, the load activated after V1 is 0.8V. The intensity of USB LED lamp are different from each tested appliance even from the same value of voltage.
due to strength of constant heat of each appliance are differ, so the output also would be different. The output from circuit could not activate a small fan because it needs at least 0.2A.

Marking point from manufacturer data as Figure 10 are the theoretical data compared to experimental output.

![Maximum Output Current vs. Input Voltage](image1)

Figure 10: Marking Point from Manufacturer Data

Based on Figure 11, it shows that there has slightly difference from experimental and typical results but since it more than 85% of typical current, so it would accept.

![Graph of Experimental and Manufacturer](image2)

Figure 11: Graph of Experimental and Manufacture

IV. CONCLUSION

Waste heat comes from household appliances can be one of the alternative energy sources as it can produce an output voltage even though it is very small. Based on the observation during conducting experiment, TEG or TEC are the most suitable medium to act as generator where it can produce electricity from waste heat directly by using Seebeck effect method. DC-DC booster circuit designed has successfully increased the voltage from TEG or TEC thus activating the USB LED lamp during experiment. The major findings of this project are the relationship of the temperature difference and the voltage produced where the temperature difference is proportional to the voltage produced. Besides that, there are several others factors contributing to the performance of electricity output such as surrounding temperature, cooling system, and design configuration. In conclusion, the project of development of waste heat as new alternative energy source had succeeded.

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REFERENCES