DEVELOPMENT AND PERFOMANCE OF COGENERATION BIOMASS STOVE INTEGRATED WITH THERMOELECTRIC GENERATOR (TEG)

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DECLARATION

This work has not previously been accepted in substance for any degree an is not being concurrently submitted in candidature for any degree.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRAK

Penggunaan dapur biomas adalah di seluruh tempat di kawasan luar bandar di negara yang sedand membangun. Ia adalah penting untuk menggunakan semua sumber yang ada tanpa membiarkan ia daripada bazir begitu sahaja seperti haba buangan daripada dapur. Sebuah dapur roket telah dibangunkan di USM untuk memasak. Dapur tersebut telah direka khas untuk befungsi tanpa asap. Tetapi dinding dapur masih terlalu panas dan haba hilang ke persekitaran. Penjana elektrik skala kecil untuk kegunaan rumah seperti mengecas telefon, tab dan komputer riba tidak ada di pasaran. Penjana kuasa kecil sebegini adalah satu keperluan penting yang perlu dibangunkan berdasarkan dapur roket yang khusus untuk penjanaan kuasa. Oleh itu, dua dapur biomas yang diubah dengan tujuan yang berbeza telah dibangunkan di bengkel kami dan prototaip telah dibina. Satu dapur memberi tumpuan kepada prestasi yang lebih baik dalam pemasakan, dan pada masa yang sama menjana kuasa. Satu lagi dapur memberi tumpuan kepada pencapaian lebih baik bagi penjanaan kuasa, dan boleh digunakan untuk memasak pada masa yang sama. Satu modul dipanggil penjana termoelektrik (TEG) telah bersepadu dengan dapur untuk menjana tenaga elektrik daripada haba buangan untuk kuasa peralatan elektrik asas. Kertas kerja ini membincangkan data yang diperolehi daripada eksperimen yang menggunakan komersial TEG bandingkan dengan data teori untuk kedua-dua dapur. Akhir sekali, dua eksperimen yang berbeza dijalankan menggunakan TEG dengan dapur dibentangkan menunjukkan bahawa TEG menjana 2.15W dan kuasa 4.69W daripada setiap dapur dan sedia untuk digunakan sebagai penjana kuasa di kawasan luar bandar.

ABSTRACT

The usage of biomass stoves is all over the place in rural area of developing countries. It is essential to use all the available resources without letting it go waste such as the waste heat from the stove. A rocket stove has been developed at USM for cooking. The stove has been designed to be smokeless and high efficient stove. But the wall of the stove is still hot and heat is lost to the surrounding. Small scale independent electrical generator for home usage such as charging phone, tab and laptop is not available. This is a need to develop a small scale power generator based on rocket stove which dedicated for power generation. So, two upgraded cogeneration biomass stoves with different purposes has been developed in our workshop and prototypes have been built. One stove focuses on better performance of cooking, and at the same time generating power. Another stove focuses on better performance of power generation, and can use for cooking at the same time. A module called thermoelectric generator (TEG) has integrated with the stove in order to generate electricity from the waste heat to power the basic electric equipment. This paper discusses the data obtained from the experiment using commercial TEG compare with the theoretical data for both stoves. Lastly, two different experimental set up using the TEG and the stoves is presented showing that TEGs generate 2.15W and 4.69W power from each stove and ready to be used as possible power generator at rural area.

1. Introduction

Even though technology is constantly developing, there are people still surviving in places that do not have electricity. It will cost tremendously for the government to supply the electricity to the rural area like that. So people at those places are surviving with kerosene lamps at night and biomass stove for cooking.

Biomass is the primary fuel for cooking in rural areas of developing countries. People in rural areas still rely on natural resources like wood, cow dung, agricultural waste as fuel and build the cook stove with bricks and clay and they still use traditional three stone cook stoves made up of brick and clay and use biomass/wood as fuel. Generally open fire stoves have been used for burning biomass fuel. Using these low efficiency open fire stoves will lead to inefficient use of fuel-wood supplies [1]. The open fire stoves also emits some health damaging air pollutants.[1,2]. Replacing the traditional open fire stoves with some improvisation can prevent the people in those rural area from damaging their respiratory system besides saving the fuels [3,4].

Nearly 1.6 billion people have lack of access to electricity [5] and most of them are from rural areas. In developing countries only few villages are equipped with electric lighting and the remaining houses still use candles. In the market, there are small scale solar power generator available for purposes such charging phone and etc.

Integrating Thermoelectric Generator (TEG) to a biomass stove is investigated to provide electricity. For a biomass stove that uses wood as fuel, the surface temperatures are likely can reach the range 150-350 °C (423-623 K). There are TEG modules commercially available in market that are claimed to operate safely without causing any disturbance up to 800 °C (1073 K) (CMO-32-62S Cascade). Generating power via using TEG has been proposed by Min and Rowe [6].

The advantages of a TEG in integrating with biomass stove are as follows. It uses heat loses from the stove, it operates silently since it's not involving any moving parts, very low maintenance, and most importantly the TEG works when the stove is on, day and night in good or in rainy weather unlike solar panels.

Research has been done by considering the possibilities of integrating TEG modules to commonly available wood-fired stoves in rural area where the electricity supply is not stable and face constant disruption [7]. But the drawback of the research was the performance of cooking is not efficient. Economic performance of using TEG in power generating system has been evaluated by the authors [8].

Another study has been done on the feasibility of incorporating a TEG made up of bismuth-telluride materials with a stove by creating a power generating system using waste heat that emits from the stove [9]. From the research, when the temperature difference is around 150 °C the system generates approximately 2.4W which is ample to utilize for radio or any low power electric equipment.

However the existing systems only made up of permanent stoves which built with bricks and only focuses on better efficiency of the stoves. This limits the performance of the TEG in generating power. In this paper, a study has been done on two cogeneration biomass stoves which dedicated for better performance of cooking and effective performance on power generation.

2. Material and Methodology

2.1. Thermoelectric Generator (TEG)

TEG in solid state energy device which converts heat directly into electricity by means of the thermoelectric effect. An analysis on TEG and thermoelectricity is presented by Rowe [11] and Hodes [12]. The efficiency of TEG is 5% according to Champier et al [14]. Figure 2.1 shows the basic principle of TEG [14]. The working principle of TEG explained well by Hsu et al [13]. Seebeck coefficient model is the method used and few factors considered in its calculation, such as parameter under zero load, realistic temperature and pressure levels to estimate the TEG's behaviour in practical situation. This is important because TEG works oddly under load conditions. Seebeck coefficient, a αeff is calculated by applying a fixed temperature difference across the TEG and varying the load resistance. The power is obtained from Eq. (1).

$$P_{elec} = (\alpha_{eff}\Delta T)^2 \, RL \,/\, (RL + RTEG)^2 \qquad (1)$$

Theoretically, maximum power is obtained when the TEG resistance matches the load resistance; i.e. when R_{TEG}= R. Some specifications for both TEGs used in this study are provided in Tables 2.1 and 2.2.

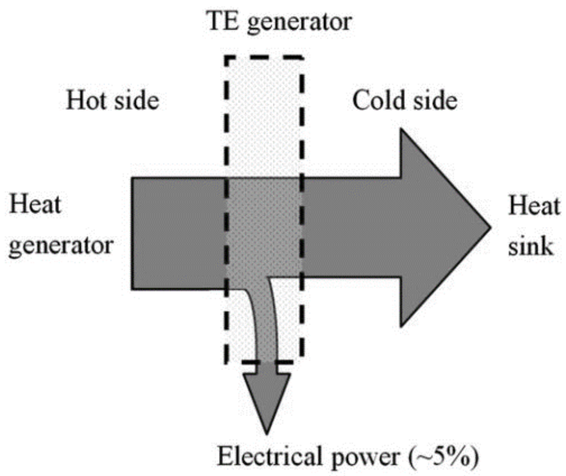

Figure 2.1. Basic principle of a TE power generator

Table 2.1. TEG SP1848-27145 Supplier specifications

Dimensions	40 mm x 40 mm
Open circuit voltage	4.8 V
Internal resistance	2.4 Ω
Match load max. output power	3.2 W
Heat flow through the module	~83W
Maximum temperature of hot side	200 °C

Table 2.2. TEG241-1.4-1.2 Supplier specifications

Dimensions	54 mm x 54 mm
Open circuit voltage	11.4 V
Internal resistance	4.5 Ω
Match load max. output power	7 W
Heat flow through the module	~120.7 W
Maximum temperature of hot side	200 °C

2.2. Stove A

In this study, two stoves has been designed and fabricated. Stove A which dedicated for better performance of stove and Stove B dedicated for effective performance for power generation.

Fundamental factor that was considered for both stoves for this study was the surface of the stove's wall has to be flat for integrating TEG. The stove was designed by using Solidworks based on rocket stove which developed at USM. The solidworks design branched into which were stove's main body and feeding chamber shelf. The main aim for stove A is increase its performance in cooking. So that the heat that is produced from burning wood should not be lost easily. Hence, a jacket is incorporated as shown in Figures 2.3 and 2.3.

Hollow pipe of Mild Steel with dimensions of 100 mm x 100 mm was chosen as material for the stove. The height of the tower chimney and the length of feeding chamber was 300 mm and 200 mm respectively. Figures 2.2 and 2.3 show the exploded and assembled view of the stove, jacket and grate.

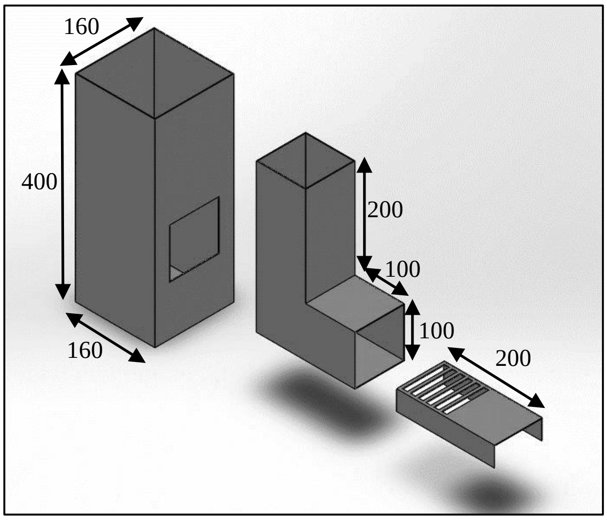

Figure 2.2. Exploded view of Stove A

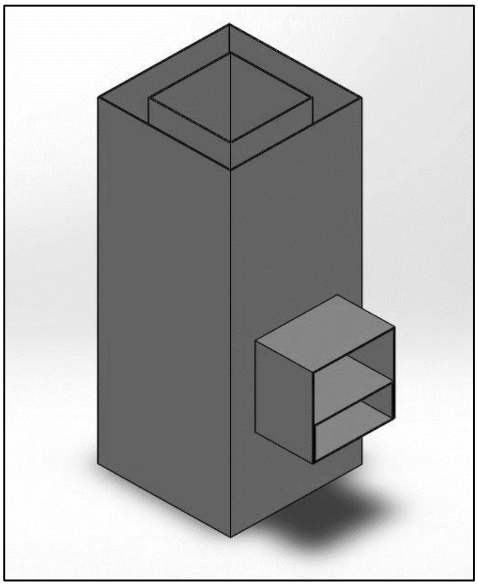

Figure 2.3. Assembled view of Stove A

The grate was designed so that the wood can be placed on top of it and allow air to flow from the bottom of the grate to produce an air draft inside the chamber. The length of the grate is exactly the same as feeding chamber which is 200mm. There are 6 slots on grate which allow the air to flow through and to let the ash from the wood to drop. For the jacket, a sheet metal of 1.5mm thickness was used. The height of the jacket is 400mm and the width is 160mm for all the sides.

2.3. Stove B

Some changes in design of stove B have been made compared with stove A as shown in Figure 2.4. The outer jacket was removed since this stove is dedicated for power generation, and the shape of feeder chamber is inclined to ease the feeding process of fuels such as pellet woods which in very small size. The feeder chamber will be closed always except during the feeding process with a lid so that no air will flow through it. An air funnel designed under the feeder chamber allows air to flow to the combustion chamber. A grate with slots was designed to place the wood and allow the air flow through it.

Stainless steel 1.5mm thickness metal sheet was used has material for this stove to enable better contact between TEG and wall surface.

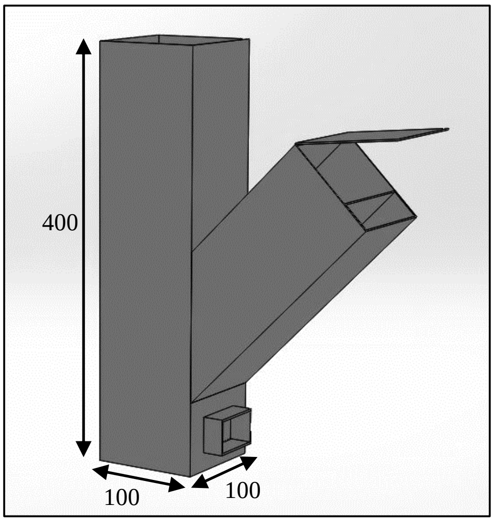

Figure 2.4. Solidworks drawing of Stove B

Mangrove wood was used as fuel for this whole experiment. Every 10 minutes interval 200g of mangrove wood was fed into the combustion chamber in order to produce constant heat. Every 200g of mangrove wood produce 0.36kW of heating power.

2.4. Stove Performance Testing

The stove's wall temperatures were taken to identify the heat loss from the stove. In this case, the time taken for the temperature to reach the highest were recorded and the test ran for 2 hours to determine the fluctuation in temperature. The wall temperatures were measured using K-Type thermocouple for both stoves.

The main part of this study is converting the waste heat energy from the stove into electrical energy. In order to perform it, two types of TEGs were used for both stove. TEG SP 1848-27145 and TEG241-1.4-1.2 were used for stove A and stove B respectively based on maximum temperature of the hot side of 150°C and 300°C respectively.

As shown in Figure 2.5 the TEG was attached on the wall of stove by using mounting and nut. Thermal paste was used between the surface of the TEG and stove's wall and heat sink.

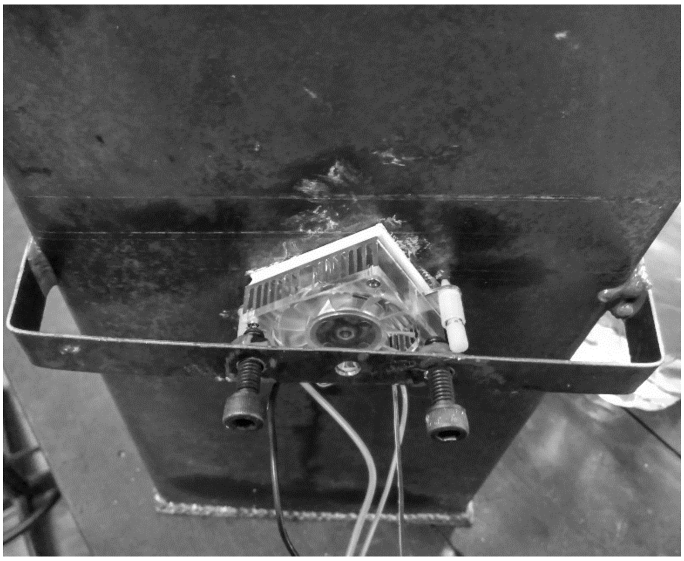

Figure 2.5. TEG mounted on Stove A

2.5. Testing of TEG

To analysis the power output from TEG, voltage and current readings were measured. Figure 2.6 shows the schematic drawing of whole connection of voltmeter, ammeter and heat sink to the TEG. Voltmeter connected in parallel meanwhile ammeter connected in series with TEG.

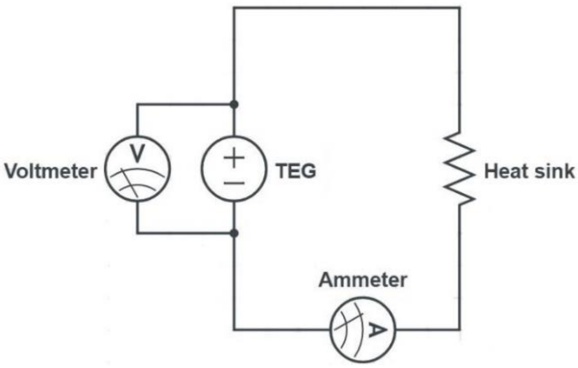

Figure 2.6. Schematic drawing of whole connection with TEG

3. Results and Discussion

Temperature of the stove’s wall is a parameter which requires choosing the proper TEG to be used on the stove in order to achieve optimum output. So the temperature along the wall of each side of the stove was measured. Figures 3.1 and 3.2 show the name of each side of the wall of the stove A and B respectively which will be used in following section.

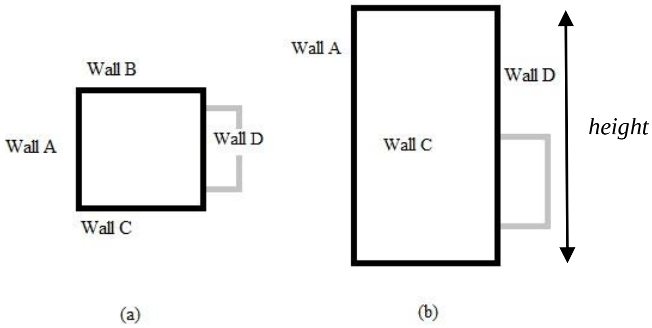

Figure 3.1. Stove A. (a) Top view. (b) Side view

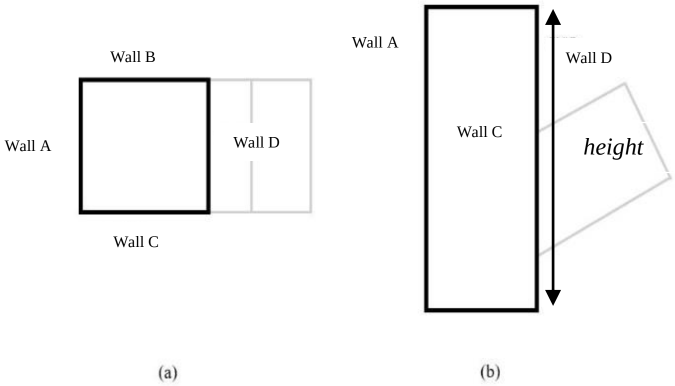

Figure 3.2. Stove A. (a) Top view. (b) Side view

3.1. Temperature profile

For Stove A, TEG SP1848-27145 was selected as the right option of TEG because the wall temperature of stove A never exceeds 160°C. In Figure 3.3, the temperature profile of each side of the wall were plotted so that it will be easier to install the TEG in the right location which provide larger temperature difference of hot and cold surfaces. The temperature measured along the middle of every wall.

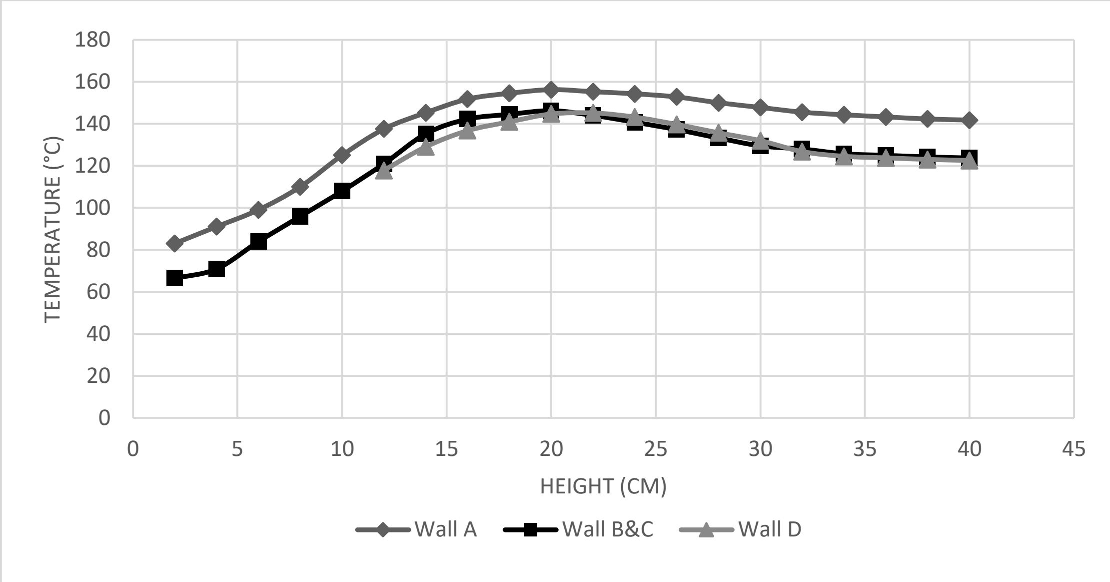

Figure 3.3. Temperature profile of Stove A

For Stove B, TEG241-1.4-1.2 was used since the wall temperature of the stove can reach near 350°C. In given temperature profile (Figure 3.4) the pattern of the graph is almost same as stove A. This is because the air inlet for both stove are the same but the difference is caused by the jacket as insulator. The temperature were measured along the middle of every wall as the previous stove.

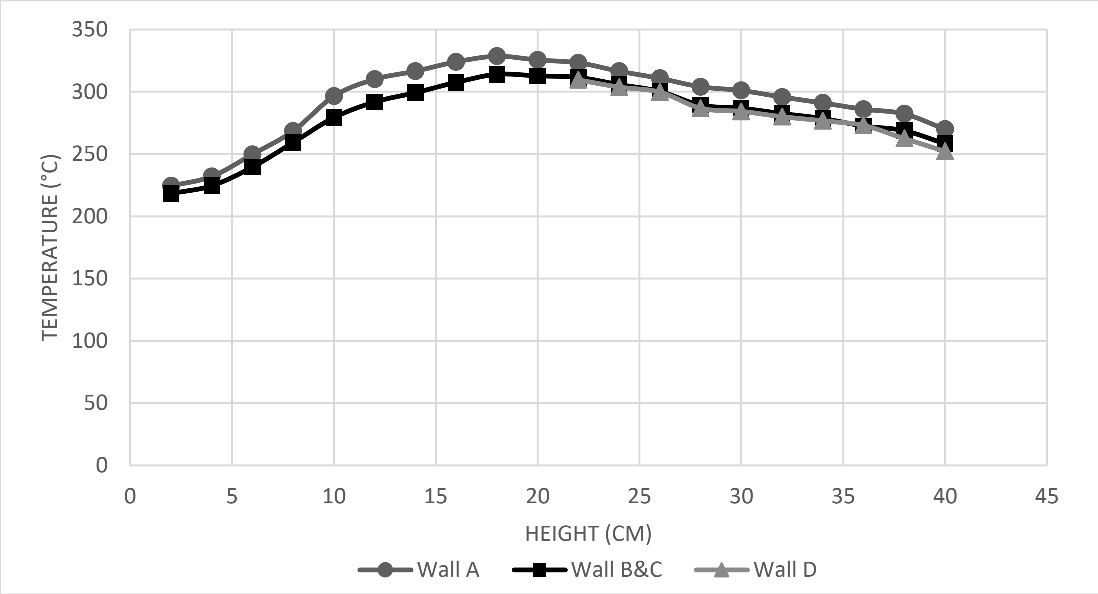

Figure 3.4. Temperature profile of Stove B

The stove's walls reach maximum temperature after 15 minutes of burning process. After the 15 minutes, the temperature of the wall remains constant with the fuel fed every 10 minutes interval. Figures 3.5 and 3.6 show the temperature of the wall reached the maximum point of both stoves A and B respectively. The reading was taken 20 cm from bottom where the temperature was maximum throughout the experiment.

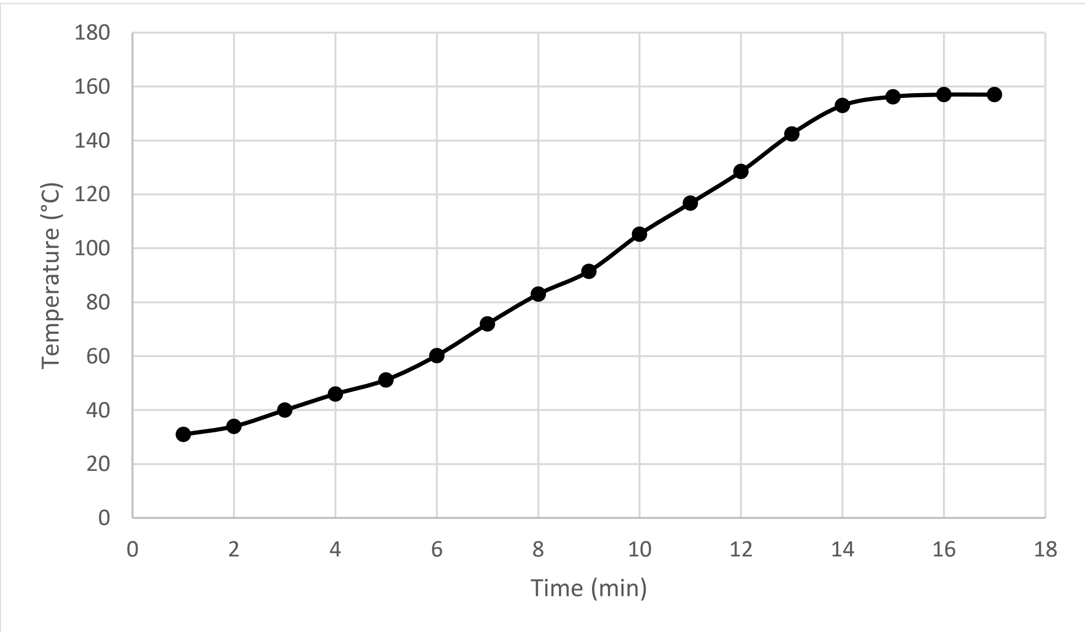

Figure 3.5. Temperature against time for stove A

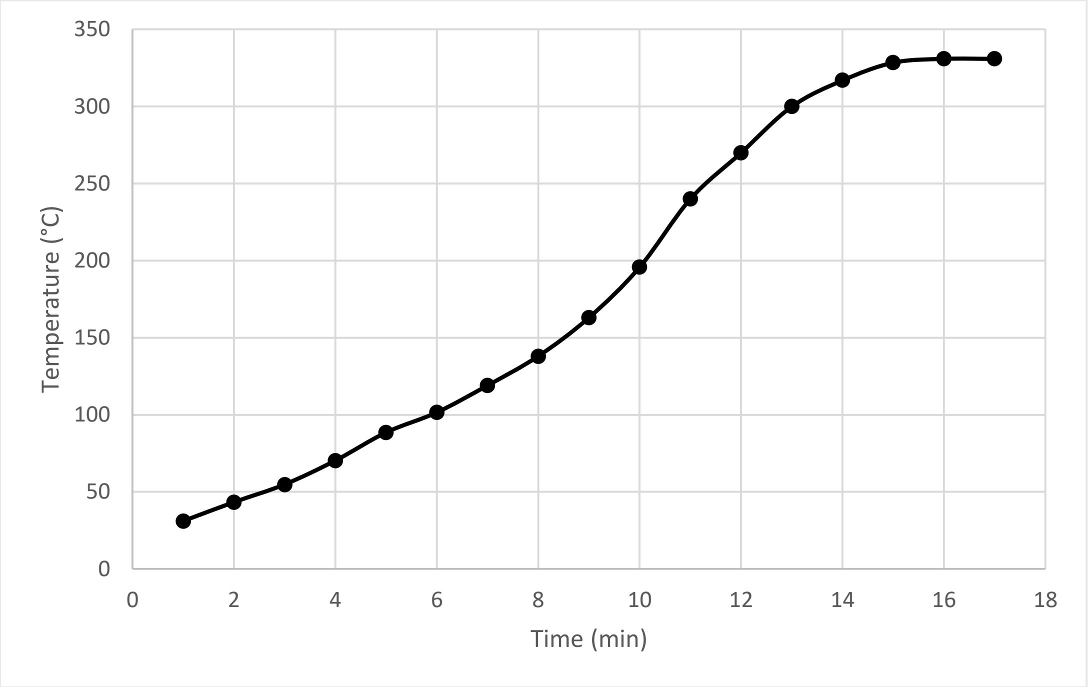

Figure 3.6. Temperature against time for stove B

3.2. Performance

Figure 3.7 shows the theoretical and experimental power output obtained as a function of temperature difference between hot surface and cold surface of the TEG for stove A. The theoretical power output continue to rise with corresponding rise in temperature difference. The experimental power output reached maximum value 2.15W at a temperature difference of about 100°C. The average deviation of the experimental power output compared to the theoretical power output is 30%.

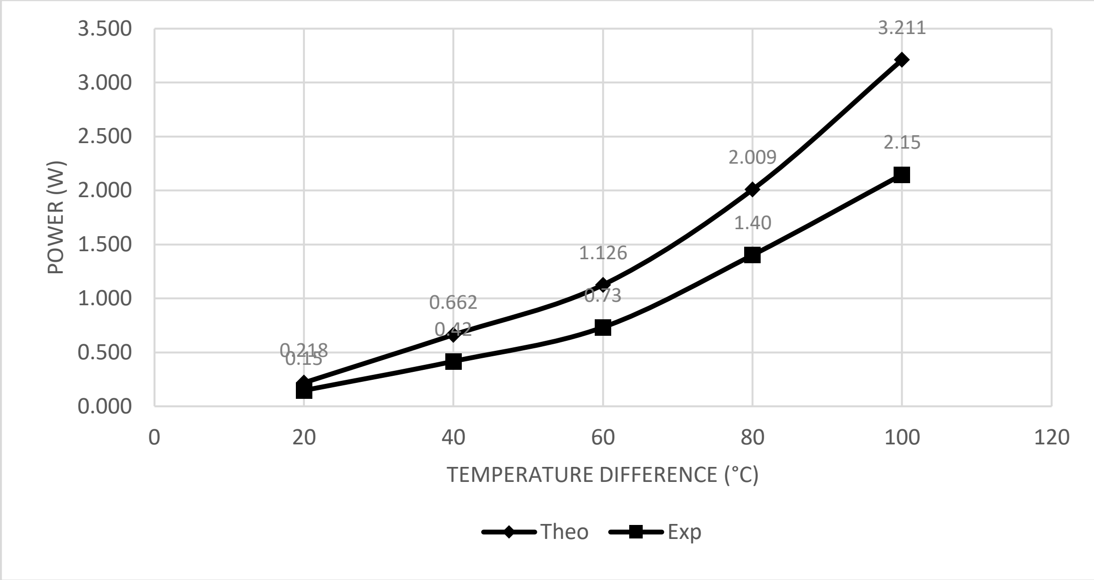

Figure 3.7. Comparison of theoretical and experimental power output for stove A

The temperature and power output measured for 2 hours to test the endurance performance of the TEG. Fluctuation in the power output when the temperature difference between the hot and cold sides of the TEG maintained at 100°C is shown in Figure 3.8 for stove A and Figure 3.10 for stove B. The reason for the fluctuation in the power output and wall temperature is the fuel. The temperature rises every time when the fuel completely burnt and declines when the fuel is fed.

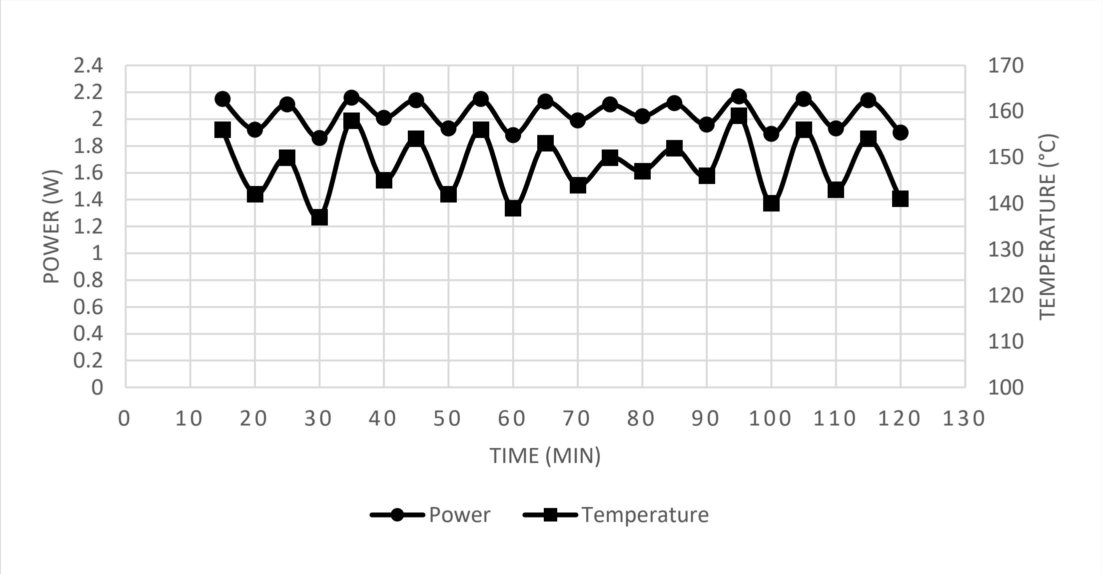

Figure 3.8. Power output and temperature against time for stove A

For stove B, the deviation of experimental power output compared with theoretical power output are shown in Figure 3.9 is almost similar as in Figure 3.7 which is in the range of 30-40%. The deviation occurs due to some unavoidable reasons such bad contact between surfaces. Although thermal paste has been used in between TEG surface and the stove wall, the contact still can be poor since the paste might not cover the whole TEG.

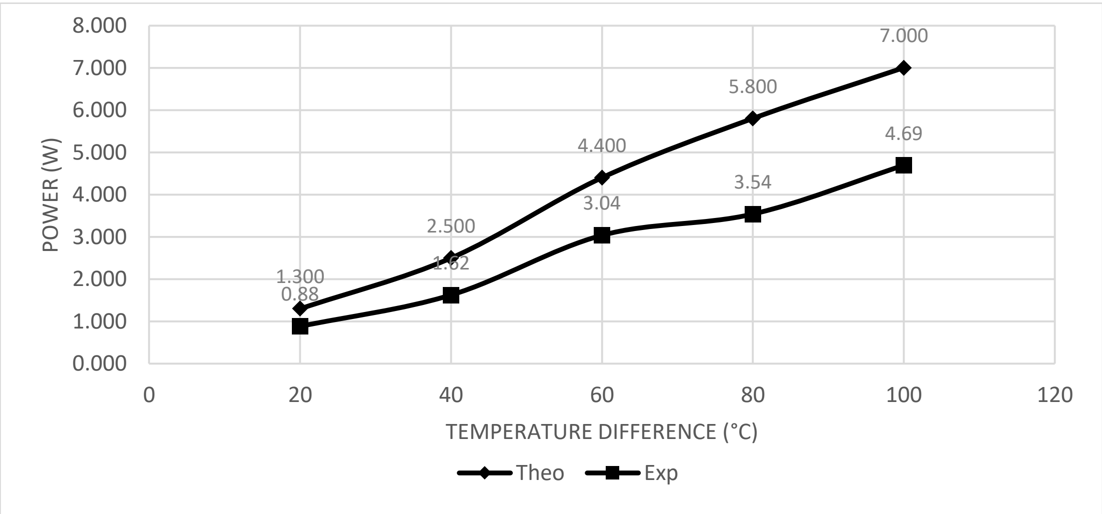

Figure 3.9. Comparison of theoretical and experimental power output for stove B

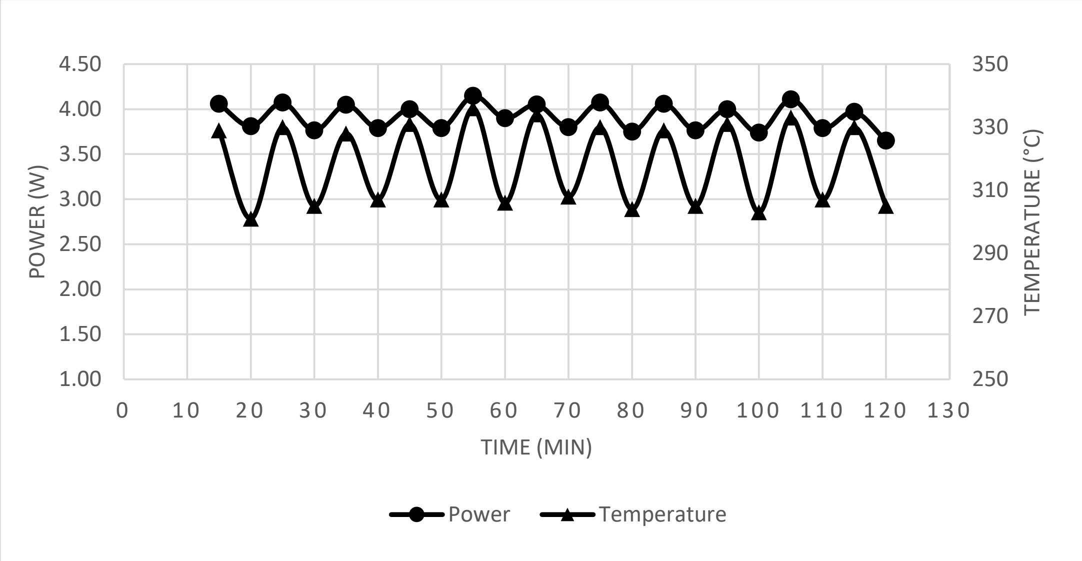

Figure 3.10. Power output and temperature against time for stove B

3.3. Potential Outcome

Throughout the experiment, the system tested with only one TEG. The generated result can be used in calculating the potential power output. Assuming that the temperature difference between hot side and cold side is maintained at 100°C, the total potential output has been calculated for both stove.

The surface area of wall A, B and C of stove A are similar which is, 64000mm^2 and the surface area of wall D is 32000mm^2. Without considering the temperature difference along the wall, the maximum amount of TEG that can fit on all wall surfaces is 140. Since only certain area produce temperature difference of 100°C, the optimum number TEG that fit the system is 78. If each TEG can produce 2.15W power (as in Figure 5), the potential power output for stove A is 167.7W.

For stove B, the surface area of wall A, B and C are similar which is, 40000mm^2 and the surface area of wall D is 20000mm^2. Stove B is different compared with stove A in terms of design so, the maximum and optimum amount of TEG that can fit in whole system is 56. If each TEG can produce 4.69W power (as in Figure 9), the potential power output for stove B is 262.64W. This value varies and depends on air fuel ratio [10] and the contact between TEG and the wall.

167W and 262W of power output from a stove considered as very fruitful for the people at rural area since they are not spending anything for the fuel and at the same time they using the stove for cooking purpose.

Examples of what can be done with the 167W and 262W are listed in Table 3.1.

Table 3.1. Electric equipment and its power requirement [15]

Aquarium	120 W
Hand mixer	150 W
Boiler, oil	200 W
Television	100 W
Computer	120 W
Light bulb	100 W
Ceiling fan	25 W
Vacuum cleaner	200 W

3.4. Summary

Stove A can be dedicated for cooking while Stove B dedicated to power generation. The reason for huge variation of wall temperature between stove A and B because stove A was fabricated with a jacket that works as an insulator to contain the heat from escaping enhances and provide better performance of stove compared with stove B. Meanwhile Stove B was fabricated without the jacket to allow more heat energy loss on the walls for power generation. Stove B provides better performance than stove A in terms of power generation while Stove A provide effective performance than stove B in terms of cooking.

4. Conclusion

This paper describes the power generated from daily routine activities like cooking. The two TEGs are easily available in market and were tested on two simple and low cost biomass stoves. The performance of the system hugely depends on the heat transfer through both sides of the TEG module; step must be taken to keep the cool side temperature lower always in order to provide bigger temperature difference. This research shows that people in rural area can benefit by using the TEG stove which can be manufactured easily in local workshop and TEG can be purchased easily. The actual power output obtained from experiment deviated in the range of 30-40% for both stoves from theoretical power output. Potential power output for stove A and B are 167W and 262W respectively. These values calculated with using the power outputs that generated from single TEG which are 2.15W and 4.69W for stove A and B respectively. Both stoves can be used by the rural people and can generate some power for their daily routine. Stove A seems to be better than stove B because not only it gain better cooking performance, it also gain power output of 167W which is slightly less than stove B 262W.

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