ANALYSIS OF MICRO GENERATOR PERFORMANCE FROM POROUS MEDIA COMBUSTION

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DECLARATION

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

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF SYMBOLS

CO	Carbon dioxide
NO_x	Nitrogen oxides
$\boldsymbol{P_{in}}$	Thermal input
Q_w	Wall heat lost of the burner
Q_e	Sensible enthalpy flowing out of the burners per unit time
Q_{oth}	Heat flow

LIST OF ABBREVIATIONS

PMC	Porous media combustion
FC	Filtration combustion
PMB	Porous media burner
TPV	Thermophotovoltaic
PV	Photovoltaic
PIM	Porous inert medium
CMM	Coordinate measuring machine
PM	Porous media
EDC	Eddy dissipation concept
ER	Emission reduction
IC	Internal combustion
CHP	Combined heat power
MEMS	Micro electrochemical system

LIST OF APPENDICES

ANALISIS PRESTASI PENJANA MIKRO DARI PEMBAKARAN MEDIA BERLIANG

ABSTRAK

Pembakaran media berliang adalah teknologi pembakaran berasaskan pemanasan bahan seramik dengan menggunakan pelbagai gas untuk membekalkan haba. Tujuan utama eksperimen adalah untuk mendapatkan data suhu daripada media berliang dan nilai voltan, arus dan kuasa yang dihasilkan oleh peltier penjana kuasa termoelektrik. Bagi projek yang betul berdasarkan model fabrikasi, lukisan CAD berdasarkan produk sebenar model fabrikasi telah dilakukan. Model CAD mempunyai tujuh bahagian iaitu media berliang, sink haba, bahan seramik, peltier penjana kuasa termoelektrik, buih porselin, penunu dan gas butana. Terdapat juga pandangan yang meletup dalam lukisan CAD untuk menunjukkan kedudukan sebenar bahagian tersebut. Untuk model rekaan sebenar, beberapa bahagian dibuat dengan menggunakan beberapa alat. Gergaji tangan mini digunakan untuk memotong silinder dan bentuk persegi logam aluminium. Walau bagaimanapun, logam keluli lembut silinder dipotong menggunakan mesin gergaji. Logam keluli lembut dikimpal pada penunu dan dua bahagian logam aluminium daripada media berliang dikimpal dengan menggunakan mesin MIG. Bahan seramik dimasukkan ke dalam logam aluminium bentuk empat segi dengan menggunakan jaring dawai bagi mengelakkan seramik bergerak. Kemudian, empat peltier penjana kuasa termoelektrik melekat pada setiap sisi media berliang dengan menggunakan gam plaster haba dan perkara yang sama berlaku pada empat sink haba yang melekat selepas peltier penjana kuasa termoelektrik untuk menyejukkan peltier penjana kuasa termoelektrik dari sisi yang lain. Analisis yang dilakukan adalah untuk mendapatkan penghasilan kuasa elektrik sederhana daripada peltier penjana kuasa termoelektrik pada suhu yang stabil memandangkan media berliang boleh mengekalkan haba pada jangka masa yang lebih lama.

ANALYSIS OF MICRO GENERATOR PERFORMANCE FROM POROUS MEDIA COMBUSTION

ABSTRACT

Porous media combustion is a combustion technology based on heating the ceramic material by using various gas to supply heat. The main purpose of the experiment was to gain data on the temperature from the porous media and value of voltage, current and power that produced by thermoelectric power generator peltier. As for proper project that based on fabricate model, CAD drawing that based on the actual products of fabricated model has been done. The CAD model has seven parts which are porous media, heatsink, ceramic material, thermoelectric power generator peltier, porcelain foam, burner, and butane gas. There is also exploded view in the CAD drawing to show actual positions of the parts. For the actual fabricated model, few parts fabricate by using few tools. Mini hand saw used to cut the cylinder and square shape of aluminum metal. However, cylindrical mild steel metal cut using saw machine. Mild steel metal welded to the burner and two part of aluminum metal of porous media welded by using MIG machine. Ceramic material put inside the square shape aluminum metal with the used of wire net in order to prevent the ceramic to move. Then, four thermoelectric power generator peltier stick to every side of porous media by using thermal plaster glue and same goes to four heatsink that stick after the thermoelectric power generator peltier in order to cool the thermoelectric power generator peltier from other side. The analysis done is to gain the moderate electrical power production from thermoelectric power generator peltier at stable temperature since porous media can retain heat at longer period of time.

CHAPTER 1

INTRODUCTION

1.1 Overview of Porous Media Combustion

Porous media burner (PMB) or porous media combustion (PMC) is a filtration combustion process in which combustible gas and an oxidising chemical travel via porous filtration combustion (FC) [2]. The combined action of conduction, convection, and radiation causes thermal reflux in porous media. Premixed air reacts and releases heat, heating the solid framework in the reaction zone by gas-solid convection, then the upstream solid framework via solid heat conduction and radiation effect, and finally the premixed air via gas-solid convection and heat exchange [4,5].

As a result, PMC technology offers benefits such as high power, adjustable range, high power density, very low pollutant emission, compact structure, high fuel adaptability, and a wide range of equivalent ratio adjustment. One of the many options for increasing energy efficiency in buildings is porous media combustion (PMC), which is already commercially available for various uses [7]. For example, my project is based on converting the heat that produce by porous media combustion into electricity. The electricity can be used in various electrical products. It can be used to cook as well as create heat for space, water heating and also can be used to charge our smartphone or any gadget. PMC is a feasible and efficient technology that may be utilised in the kitchen [1]. The oil and gas industry could benefit greatly from gas-phase combustion in porous media. Enhanced oil and gas recovery, formation heat treatment for remediation of near-well-bore formation damage, and downhole steam generation for heavy oil recovery are examples of such uses.

1.2 Objectives

1. To fabricate the cylindrical porous media burner using aluminium metal and chosen ceramic material.
2. To convert heat from porous media burner with ceramic material to electrical energy using thermoelectric power generator peltier.
3. To maintain the stable thermal heat from porous media burner to aim for high electrical power production.

1.3 Problem Statement

Porous media burner (PMB) is widely used in a variety of practical systems, including heat exchangers, gas propulsion, reactors, and radiant burner combustion. However, the PMB used for electrical energy generation is still lacking. Thus, the study on porous medium burner based on porous media combustion that converts thermal heat into electrical energy by using micro power generator is yet to be explored. There are also issues where different types of fuel will affect the combustion inside the generator. The better heat provided will give better result on electrical energy to be generate. Then, the fact that the thermoelectric power generator peltier limited heat that can be absorbed also need to be considered.

1.4 Scope of the project

For this final year project, the scope of work is based on experimental and fabrication. The experiment is to convert heat from porous media burner into electrical energy. The project is to fabricate the medium of porous media burner to keep on my project. The design of the porous medium burner has been done earlier in orderto fabricate. The fabrication uses the material of aluminium tube with cylinder and square shape. Then, the thermoelectric power generator peltier will be used to convert heat energy into electrical energy. Overall, the scope of the project deals with the design, fabrication and test of porous media combustion and its performance of converting the thermal heat into the electrical energy by using thermoelectric power generator peltier.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Thermophotovoltaic (TPV) generation of energy has resurfaced in recent years, thanks to advancements in micro manufacturing technology and advances in the areas of selective emitter and low band gap PV cells. The micro-TPV system, as an unique energy conversion device, consists primarily of a fuel source, a combustor with its wall serving as an emitter, a selective filter, and a PV array [2,13]. Power supplies for the gadgets stated above must be portable, have a short charging time, be long-lasting, have a high energy density, and be ecologically friendly. The chemical batteries also have been the primary source of power for these gadgets in the past, but they have the disadvantage of having a low energy density.

Following these early attempts, several researchers conducted tests, and the models of combustion within porous burners have slowly become more sophisticated as computing capabilities have developed. They characterised combustion as a one-dimensional issue with spatially dependent heat generation, and their analytical model matched reported solid temperature profiles quite well [16].

The present and planned pollution laws to preserve a clean environment have driven recent study and development in the field of combustion systems design. This should be done in addition to the initial goals of boosting combustion efficiency, lowering energy consumption, and ensuring consistent combustion under a variety of situations [8]. As a result, new combustion processes have been proposed to replace the traditional and traditional ones. PIM (porous inert medium) combustion is becoming increasingly relevant, both in terms of theoretical interest and practical usefulness.

Next, the majority of coordinate measuring machine (CMM) is unusable due to low drained methane concentrations and frequent changes in methane concentrations and flow rates, which combined hinder conventional procedures from effectively using CMM which allow them to proceed to PIM instead [20]. The porous medium combustion technology is superior to traditional free flame combustion technology because it has a wider lean burn limit range, higher burning efficiency, lower pollutant output, and faster flame speed, all of which are suitable for combustion and use of low-concentration CMM.

2.2 Theoretical

The numerical method has been focused as the theory of the porous media combustion where the research more to control the way of experiment. The numerical model used in this research was based on a convectional combustor with a rectangular channel and a schematic diagram of a micro combustor with 316 L stainless steel walls [20]. Allowing the premixed H2/O2 stream to pass through the tiny combustor starts the entire combustion process. To mimic turbulent flow with a complex chemical reaction mechanism, the EDC model was utilised. The DO radiation model was used to cope with the radiation of the inner PM [5]. Mixed thermal boundary conditions were provided to the combustor walls. The velocity boundary conditions for the micro combustor's inlet were set, as well as the flow rate and mass fraction. The fluid area was given a porous zone border condition, and the outflow boundary condition was defined at the exit.

Next, focus on the next theory where three burners' thermal performance is investigated. The law of conservation of energy states that,

$$P_{in} = Q_w + Q_e + Q_{oth} \qquad \text{------------------ Equation (1)}$$

Where P_{in} is thermal input of fuel and air, Q_w represents wall heat loss of the burners, Q_e is the sensible enthalpy flowing out of the burners per unit time, which is calculated by using temperature and equilibrium gas compositions of the exhaust gas, and Q_{oth} represents other heat flow [17].

Then, referring to model the combustion coupling with solid temperature equation and detailed homogenous reaction mechanism of methane, a 2-D axisymmetric geometry was used. The simulation was created with the help of the FLUENT software suite. We used the user's manual to find the governing equations, such as continuum, momentum, gas energy, and species transport equations. The SIMPLE algorithm was used to solve the problem numerically, and it was based on an implicit, steady arrangement with a structured mesh. The two-temperature model was used in the porous medium zone [18].

Different numerical simulations were run in accordance with the experimental operating circumstances. And the heat leakage via the heat-insulated walls was overlooked. The P1 radiation model is used in FLUENT to calculate radiation between the walls, and the gas radiation can be turned off by setting the absorption and scattering coefficient to 0. Heat conduction and radiation cannot be ignored in porous media, which can be viewed as a dispersed phase. Heat transmission in porous material is considered to be identical to effective heat conduction to simplify the subject [4].

2.3 Experimental

Experimental results are reported in the following sections in order to assess the efficacy of the current technique and establish the stability limits of methane–air mixture combustion in PIM ceramics at elevated pressures and temperatures. Temperature profiles along the axis of the burner are provided. These temperature profiles can be used to acquire a better knowledge of the combustion process behaviour, flame stability location, stability limitations, and other aspects of the PIM matrix under various operating situations [10]. It was also possible to determine the peak temperature in the PIM matrix throughout the combustion process, which is critical not only for combustion but also for environmental and metallurgical considerations.

The pollutant emission levels are also discussed in order to explain how operating pressure and mixture inlet temperature affect their production in PIM combustion. The temperature profiles show that for low relative air ratios, chemical energy is released rapidly at first, then in a very gradual gradient with distance until it reaches its peak value [9]. After that, the temperature drops for the rest of the PIM. The temperature gradient at the entrance of the mixture is reduced when the relative air ratio is increased.

Refer to next experiment, a cylindrical-shaped PM burner was used. The PM burner's entire system is depicted in the layout diagram and photographic photos. The burner was divided into two parts which is top and bottom. The upper zone served as a reaction zone, where combustion took place, while the bottom zone served as a pre-mix zone [12]. The reaction zone was made of alumina foam, and the pre-heater was made of porcelain foam. Two pre-mixing operations were performed on the infused air. The wire steel mesh-lined mixing chamber, placed slightly below the burner housing, helped to mix air and fuel before it entered the burner encasement. The wire mesh increased the amount of turbulence in the flow, which resulted in additional premixing effects. Another chamber for the premixing effect is located at the confluence of butane gas and air [12].

The lowest amount of butane necessary to run the burner was initially estimated using the trial-and-error method of altering the airflow rate. The correct ER was designed to let the burner to create the necessary flame while using the least amount of fuel possible [11]. The combustion wave began when the premixed butane air mixture at the bottom of the burner was ignited.

On the one hand, as the equivalence ratio for the fixed air flow rate was increased, the heat released by methane combustion increased due to the increased methane flow rate, resulting in higher temperatures in the reaction zone and post-reaction zone, as well as more heat recirculated to the preheating zone from the reaction zone, possibly causing the increased temperature in the preheating zone [5]. On the other hand, as the equivalence ratio for the fixed air flow rate grew, the overall gas flow rate entering the burner increased as well, potentially resulting in less heat per kilogram premixed gas mixture and a lower temperature in the preheating zone. Under the same equivalency ratio and air flow rate, it was discovered that the combustion wave velocity was higher for larger diameter pellets, since more heat was transmitted from the reaction zone to the direction of combustion wave propagation due to the larger porosity [4].

The wave velocity increased within the range of the wave velocity less than zero while decreasing within the range of the wave velocity larger than zero when the air flow rate was increased from 1.2 Nm3/h to 1.8 Nm3/h for the fixed equivalency ratio and diameter of pellets [12]. On the one hand, combustion heat increased as the gas flow rate increased, resulting in more heat transfer from the reaction zone to the wave propagation direction; on the other hand, the heat obtained per kilo gramme gas reduced as the gas flow rate grew.

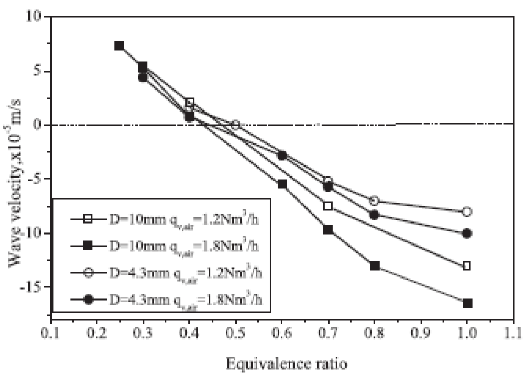

Figure 2-1: Effect of the equivalence ratio on the combustion wave velocity for different air flow rates and pellet diameters [12].

A review of porous medium combustion applications is now underway. However, several of the works have been left without citations due to page limits, but this was not done on purpose. More research is needed into the use of PMC in gas turbines, IC engines, combustion of low-thermal-value gaseous fuels like producing gas, heat exchangers, district and room heating, bakery ovens, and a variety of other applications. The concept of PMC-based on combine heat and power (CHP) is a fantastic idea in terms of energy efficiency and environmental friendliness [16]. Furthermore, the recent introduction of micro and meso-scale applications is a potential advancement in PMC technology, since it will result in tiny combustion systems for MEMS (micro electromechanical system) applications [9]. All of the aforementioned fields have a clear need for more study and a large scope for it.

2.4 Theoretical problem and solution

The necessity for high efficiency and clean combustion technology is becoming increasingly urgent as a result of environmental contamination and the rapid depletion of fossil energy resources. For many years, porous medium combustion (PMC) has been studied in order to develop these environmentally beneficial energy conversion technologies [16]. Heat transmission is facilitated by the PMC through heat conduction and radiation inside inert solids, as well as species diffusion due to reactant dispersion flowing through porous media. Micro porous media combustor was developed in this study to compensate for the drawbacks of free flame micro combustor [14].

As a result of these early endeavours, numerous researchers have conducted tests, and models of combustion within porous burners have constantly gotten more sophisticated as computing capabilities have developed. The impact of important factors such as porosity, hydrogen to oxygen equivalency ratio, mixture flow rate, and porous media materials on micro scale combustion were examined using 3D numerical modelling in this micro combustor. A two-dimensional geometric burner model was created. This sculpture was made up of two ceramic foam portions with dramatically varied pore scales. Stable solutions are achieved by solving the transient governing equations with the commercial programme FLUENT [17]. In FLUENT, the energy equations in porous media could only be solved using a single temperature model, assuming the solid and gas were in thermal equilibrium.

2.5 Experimental problem and solution

The demand for portable power sources with high energy density and lengthy working life has increased due to recent improvements in tiny scale electric gadgets. The present and planned pollution laws to protect a clean environment have prompted recent study and development in the field of combustion systems design. This should be done in addition to the initial goals of improving combustion efficiency, lowering energy consumption, and ensuring consistent combustion under a variety of operating situations. With the rapid development of micro-electromechanical systems (MEMS), the demand for miniaturized power source with higher energy density becomes more urgent [19].

As a result, new combustion processes have been proposed to replace the traditional and traditional ones. PIM (porous inert medium) combustion is becoming increasingly relevant, both in terms of theoretical interest and practical application. Because of its unique features in combustion, Porous Media (hence referred to as PM) has proven to be dependable. These include faster burn rates, a wider power dynamic range, and lower CO, NOx, and soot emissions, all of which are harmful to the environment [9]. Then, a micro-TPV system developed at the National University of Singapore (NUS) consists of a heat source (micro-combustor), an emitter, a dielectric filter and a PV cell array [2].

CHAPTER 3

METHODOLOGY

3.1 Introduction

Overall projects consist of three different method in order to complete. The first method is to fabricate the model of porous media combustion by using the aluminum metal as the main part. However, there is still a few parts that need to be fabricate. Second method is to do the experiment to collect the data from the fabricated model that consist of temperature, voltage, and current reading as the results. The reading was taken in laboratory and by using the tools that the laboratory provides. Next, the final method is to draw CAD drawing of the overall fabricated model by using the SolidWorks software including the assembly and exploded view. However, some of the CAD model parts are not exactly having the same measurement.

3.2 Fabricate Model

Figure 3-1: Aluminum metal

Fabricate model start with choosing the aluminum metal as the material was proven to stay shiny and the weight is light compared to other metal in term of long usage. The aluminum metal is easy to be shaped as desired since it is easy to be cut by using saw. Figure 3.1 shows the aluminum metal before it was cut in order to reduce the length of the metal.

Figure 3-2: Two aluminum metal combined

The figure above shows that the two part of aluminum metal was combined, and the length of the metal has been shortened. Then, both parts were welded together to form the main part of the project which is the porous media.

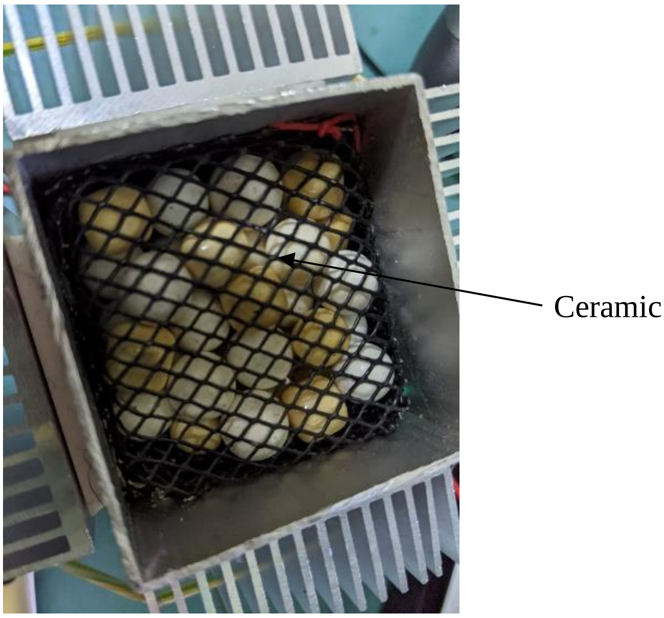

Figure 3-3: Ceramic material

After completing the porous media, the ceramic was put in the square shape aluminum metal. Actually, there is other material in between the ceramic and circle shape aluminum metal which is porcelain foam that can be refer at the Appendix C. This is to prevent the direct heat from the butane gas to the ceramic material. The ceramic contains of two different material.

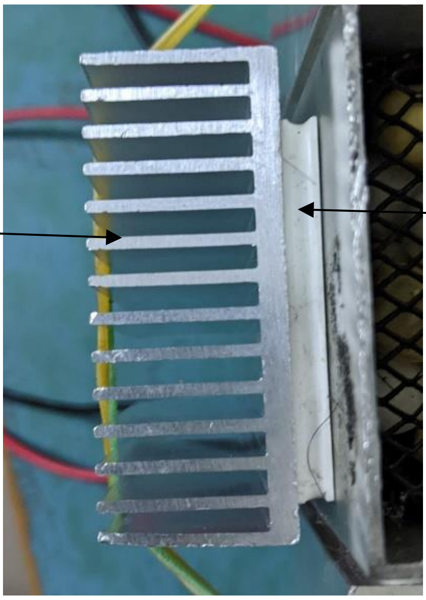

Figure 3-4: Thermoelectric power generator peltier and heatsink

Thermoelectric power generator peltier placed to four side of the aluminum metal as the heat spread from the ceramic to the aluminum metal. The heatsink placed on every peltier in order to absorb the heat from the peltier and spread it to surrounding. This is because the peltier become more efficient when one side is hot, and the other side is cold. The more temperature different between both sides, the more efficient the peltier become.

Figure 3-5: Burner

The burner is the main part to supply heat to the porous media. The cylindrical steel with the material of mild steel was welded to the burner in order to provide the place to porous media to stand. This is to make sure the porous media is in stable condition when doing the experiment.

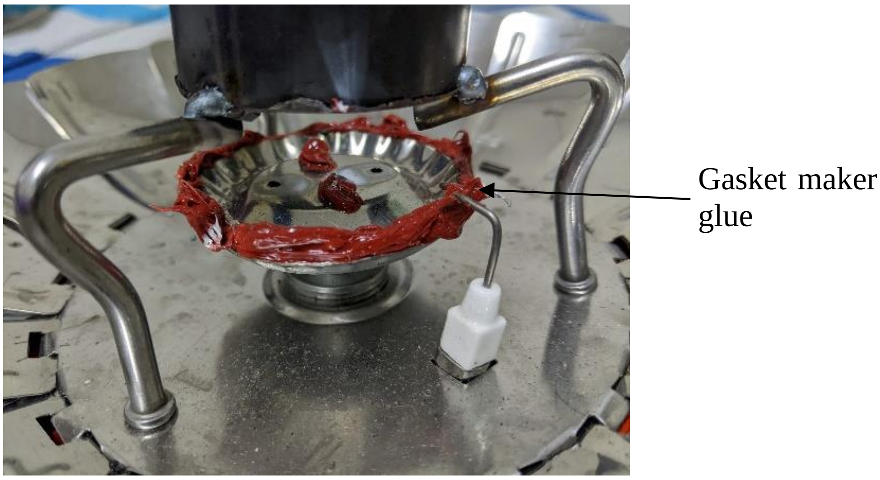

Figure 3-6: Glue the burner fire holes

The gasket maker glue used to close the original holes from 4 to 2 holes in order to reduce the fire produced and prevent too much heat to the porous media. Since the peltier can only receive a certain temperature which is below 200˚C expected. The gasket maker glue can withstand the heat to 650˚F which is equivalent to 343.3˚C.

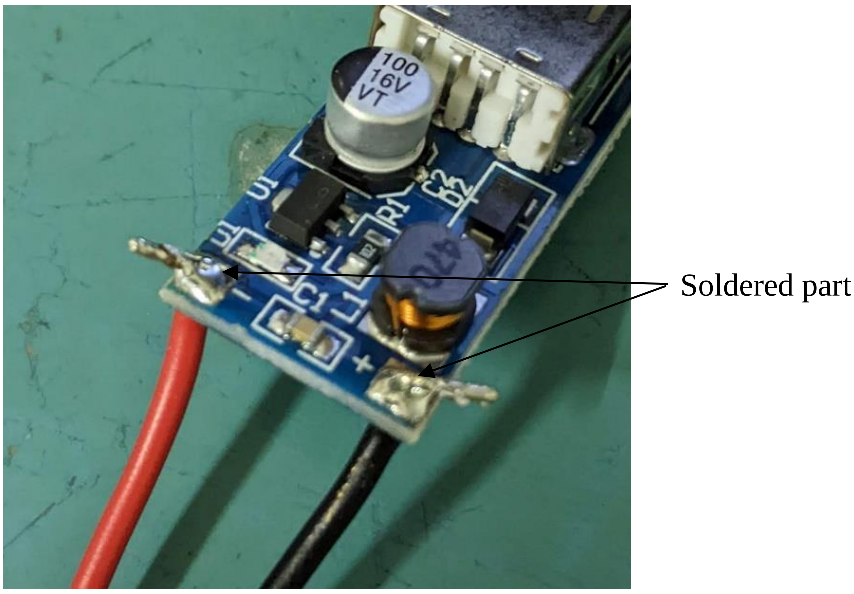

Figure 3-7: Soldered USB module

The final part of fabricating the model was to use the USB model in order to charge smartphone. However, the USB module was unable to charge the smartphone due to less power output. There was voltage loss when the USB cable put to the module as the phone detect the voltage even though the current does not affect as the voltage does. The module used to convert the voltage from 0.9V to 5V by boosting the voltage to maintain at 5V.

3.3 Experiment

The aim of this experiment is to measure the temperature, voltage and current produced by the thermoelectric power generator peltier. The voltage and current measured using two types of circuit which is parallel and series circuit. This is because both circuits produced different amount of voltage and current. Then, there is also different fire level in order to measure different heat produced to the porous media.

Figure 3-8: Infrared thermometer

The infrared thermometer used to measure the heat produced from the porous media. Infrared thermometer is accurate and fast when showing the reading. The infrared thermometer is safer since there is no direct contact to the metal surface.

Figure 3-9: Digital multimeter

Multimeter is a measurement device that can assess various electrical characteristics. The multimeter used to measure the voltage and current produced by the thermoelectric power generator peltier in unit of V and A respectively.

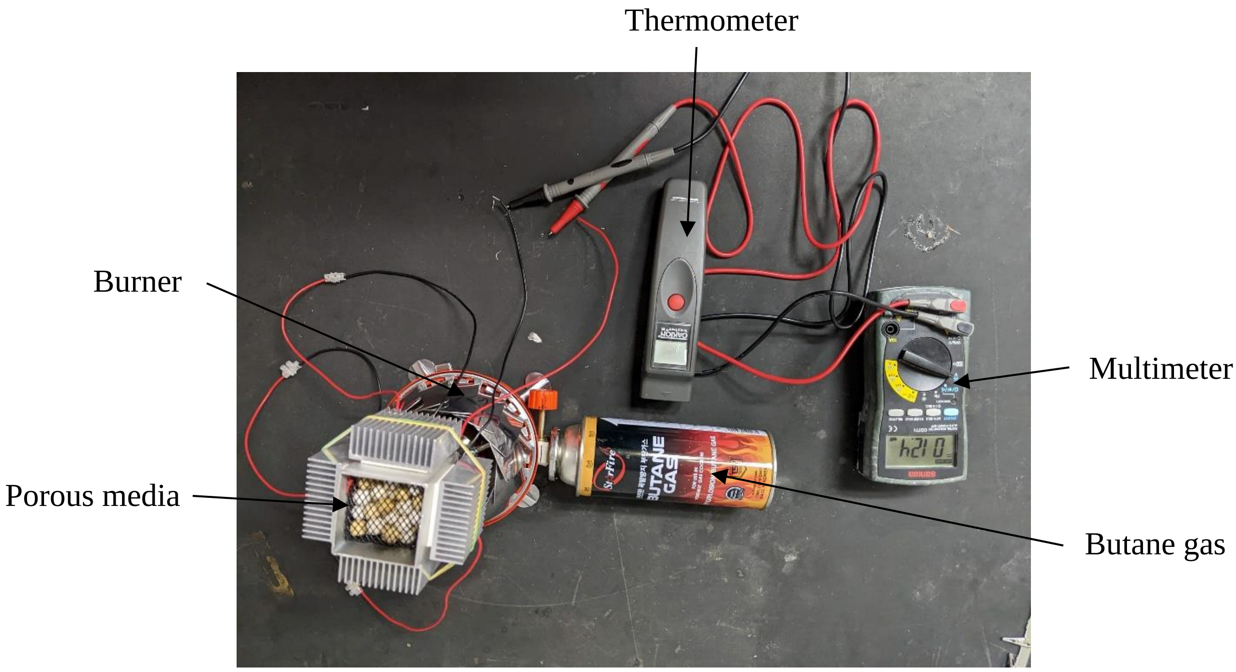

Figure 3-10: Setup data reading

Figure above show the full setup when taking the reading of temperature, voltage and current. The reading was taken every 5 minutes within one hour. There are 6 different reading since it divided to two different circuit. Then, from two different circuit there are three different fire level for different heat produced by the butane gas.

Figure 3-11: Parallel circuit

In a parallel circuit, the branches split the current such that only a portion of it passes through each branch. In a parallel circuit, each branch has the same voltage or potential difference, but the currents may differ. The voltage output is the same even combining four peltiers.

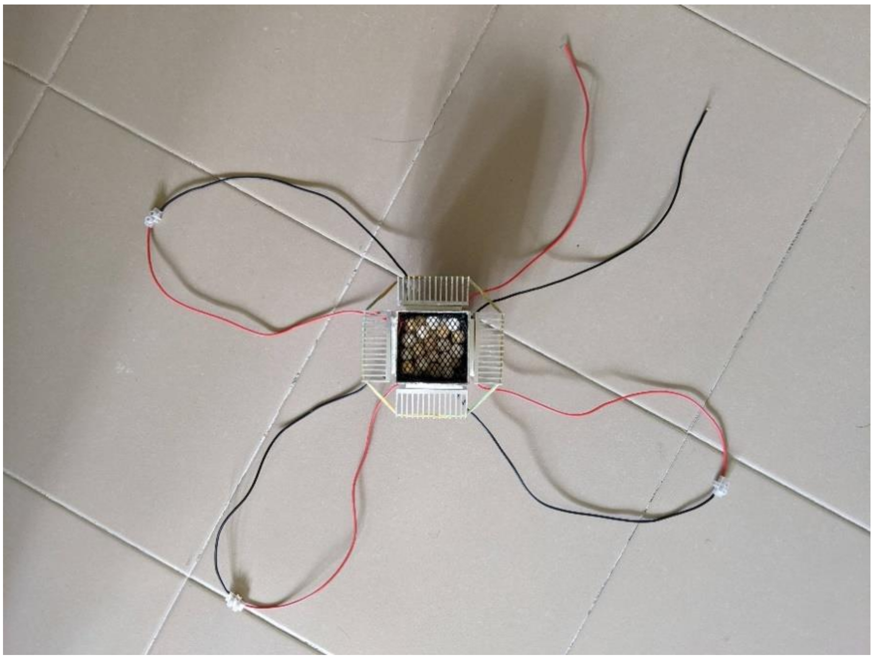

Figure 3-12: Series circuit

In a series circuit, the electric current flows through each element. As a result, the current flowing through each component in a series connection is the same. However, the voltage produced by the series circuit by combining four peltier is much more compared to the parallel circuit. Since the voltage are combining with every peltier to produced one positive output and one negative output.

Figure 3-13: Fire level 1

Figure 3-14: Fire level 2

Figure 3-15: Fire level 3

Different fire level produced different heat to the porous media that effect the reading of temperature. The different of fire level was based on how much air flow rate that produce by the butane gas. Since it is also affecting the reading of voltage and current that produced by the peltier for both parallel and series circuit.

Figure 3-16: Setup for air flow measurement

Every fire level come from different air flow of the butane gas. The flow meter was used to measure the flow rate of the butane gas. This is to measure the effect of different flow rate to the temperature of the porous media. The flow was connected using the pneumatic tube from one hole of the burner go through the flow meter. The flow meter unit is L/min that the value of the flow rate needs to multiple by two since there are 2 holes in the burner to produced fire.

3.4 SolidWorks Drawing

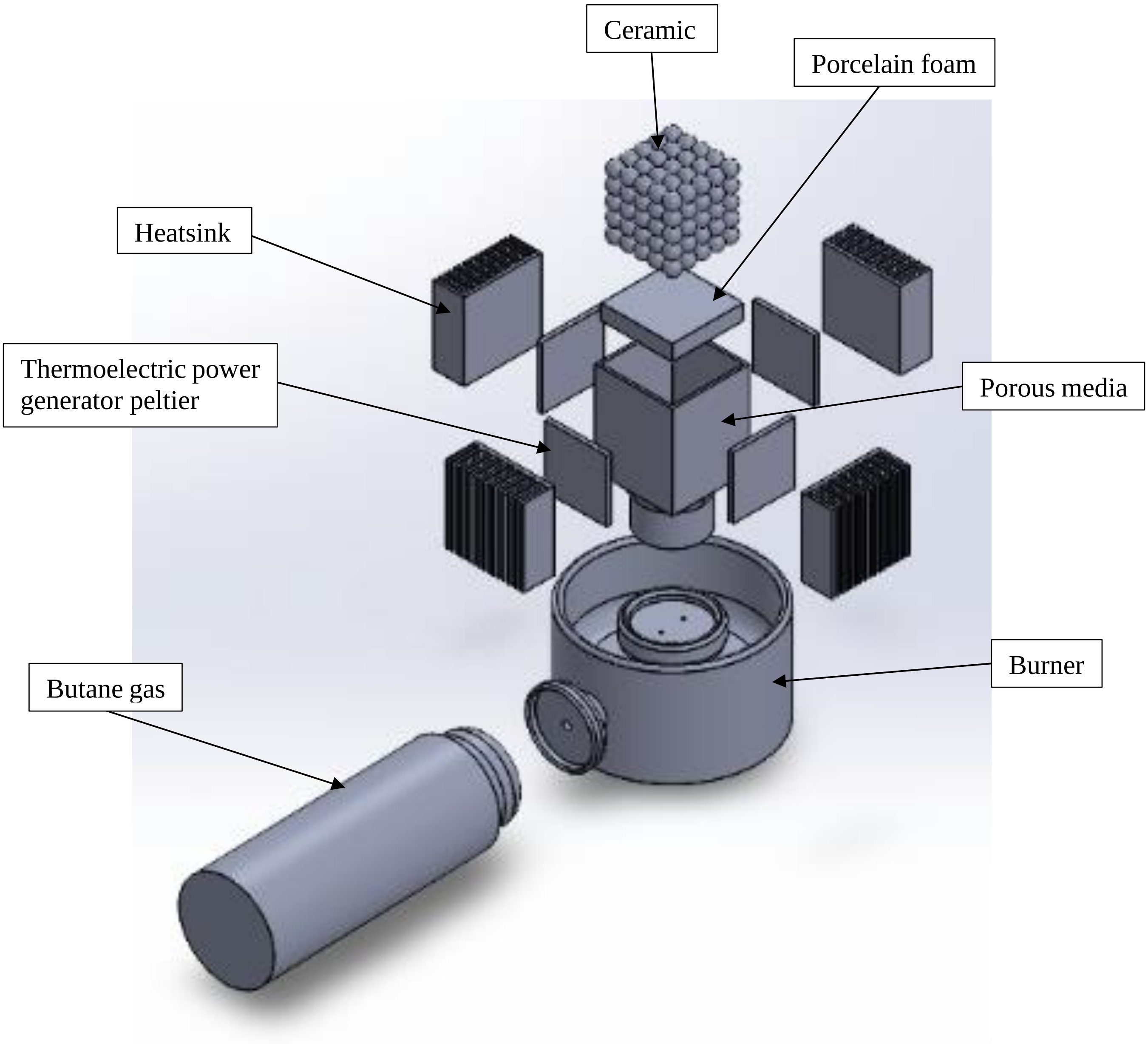

Figure 3-17: CAD drawing with exploded view

The CAD drawing was done by referring the actual product of the final year project. Not every part is exactly the same since the drawing is only for the general view of the project that may be used for the future implementation. The exploded view has been done to shows the actual positions of every part as it is the same as the actual fabricated model. There is also drawing with the exploded view that can be refer to the Appendix A. Every CAD model part and assembly can be referred to Appendix B.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The overall result gives expected result for all part of the experiment and give a very good value especially for the reading of voltage and current and power. The results consist of reading with single peltier, three different fire level for parallel circuit and three different fire level for series circuit.

Based on Table 4.1, the data was taken by using only one thermoelectric power generator peltier. This is because to measure how much output for voltage and current produce in order to have a future prediction when using four peltier.

Table 4-1: Reading with Single Peltier

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	30.2	0	0	0
5	58.8	0.610	0.120	0.07320
10	79.8	0.620	0.145	0.08990
15	89.8	0.780	0.130	0.10140
20	96.0	0.794	0.133	0.10560
25	96.2	0.759	0.130	0.09867
30	94.4	0.670	0.120	0.08040
35	94.2	0.662	0.112	0.07414
40	92.6	0.659	0.114	0.07513
45	92.2	0.653	0.110	0.07183
50	92.8	0.668	0.115	0.07682
55	92.8	0.654	0.116	0.07586
60	91.4	0.632	0.110	0.06952

Table 4-2: Air flow from 2 holes

Fire level	Air flow (L/min)
1	0.28
2	0.44
3	0.60

Parallel Circuit:

From the theoretical formula of the parallel circuit, the voltage output should be the same for every peltier and the current should be greater compared to series circuit.

Voltage, $$ET = E1 = E2 = E3 = E4$$

Current, $$ET = E1 + E2 + E3 + E4$$

Table 4-3: Fire level 1 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	28.8	0	0	0
5	52.8	0.443	0.270	0.11961
10	60.4	0.454	0.297	0.13484
15	66.8	0.502	0.271	0.13604
20	68.4	0.443	0.270	0.11961
25	71.6	0.466	0.276	0.12862
30	68.8	0.479	0.281	0.13460
35	72.8	0.490	0.287	0.14063
40	70.6	0.463	0.264	0.12223
45	69.2	0.452	0.261	0.11797
50	68.8	0.457	0.251	0.11471
55	70.4	0.461	0.259	0.11940
60	70.6	0.461	0.272	0.12539

Table 4-4: Fire level 2 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	28.4	0	0	0
5	57.6	0.602	0.366	0.22033
10	68.8	0.598	0.250	0.14950
15	78.4	0.696	0.369	0.25682
20	84.6	0.723	0.368	0.26606
25	86.2	0.720	0.357	0.25704
30	82.2	0.502	0.257	0.12901
35	80.8	0.534	0.260	0.13884
40	79.6	0.532	0.270	0.14364
45	78.4	0.522	0.258	0.13468
50	79.8	0.568	0.292	0.16586
55	83.2	0.601	0.332	0.19953
60	82.2	0.573	0.303	0.17362

Table 4-5: Fire level 3 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	30.2	0	0	0
5	63.0	0.612	0.282	0.17258
10	81.2	0.708	0.292	0.20674
15	91.6	0.649	0.355	0.23040
20	88.6	0.520	0.307	0.15964
25	88.4	0.584	0.264	0.15418
30	86.8	0.534	0.237	0.12656
35	86.4	0.683	0.320	0.21856
40	87.2	0.602	0.263	0.15833
45	87.2	0.658	0.245	0.16121
50	88.2	0.602	0.358	0.21552
55	90.4	0.663	0.417	0.27647
60	88.0	0.584	0.350	0.20440

Based on three table from the parallel circuit results, the temperature reading is forming a uniform increase within 60 minutes and maintain around 15 to 20 minutes. However, only the results on fire level 1 from Table 4.3 shows a uniform increase value of the voltage, current and power. Referring to Table 4.4 and Table 4.5, the value of voltage and current shows almost similar with a slightly different even in different temperature. It shows that the different around 10˚C do not affect a lot to the value of voltage and current produced by the four peltiers.

Series Circuit:

From the theoretical formula of the series circuit, the voltage of four peltier should be greater compared to the parallel circuit and the current should be equal for every peltier.

$$\text{Voltage,} \quad ET = E1 + E2 + E3 + E4$$

$$\text{Current,} \quad ET = E1 = E2 = E3 = E4$$

Table 4-6: Fire level 1 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	27.0	0	0	0
5	40.8	1.25	0.065	0.08125
10	47.0	1.400	0.069	0.09660
15	53.2	1.540	0.073	0.11242
20	57.2	1.630	0.076	0.12388
25	59.4	1.685	0.076	0.12806
30	62.2	1.699	0.078	0.13252
35	63.6	1.717	0.077	0.13221
40	62.8	1.720	0.080	0.13760
45	64.6	1.737	0.081	0.14070
50	65.2	1.710	0.079	0.13509
55	65.0	1.715	0.078	0.13377
60	64.4	1.698	0.076	0.12905

Table 4-7: Fire level 2 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	30.6	0	0	0
5	51.2	2.016	0.098	0.19757
10	60.0	1.930	0.082	0.15826
15	68.2	2.177	0.103	0.22423
20	73.6	2.210	0.095	0.20995
25	76.2	2.264	0.100	0.22640
30	78.6	2.280	0.098	0.22344
35	78.4	2.272	0.084	0.19085
40	80.4	2.250	0.095	0.21375
45	81.0	2.230	0.094	0.20962
50	80.8	2.205	0.096	0.21168
55	79.4	2.196	0.081	0.17788
60	80.2	2.140	0.090	0.19260

Table 4-8: Fire level 3 reading

Time(min)	Temperature(˚C)	Voltage(V)	Current(A)	Power(W)
0	30.0	0	0	0
5	55.2	2.270	0.103	0.23381
10	64.2	2.340	0.101	0.23634
15	72.6	2.452	0.094	0.02305
20	82.8	2.825	0.118	0.33335
25	78.4	2.252	0.073	0.16440
30	81.0	2.142	0.075	0.16065
35	83.0	2.401	0.084	0.20168
40	86.6	2.601	0.104	0.27050
45	86.0	2.531	0.096	0.24298
50	87.4	2.651	0.098	0.25980
55	84.8	2.304	0.097	0.22349
60	85.6	2.586	0.100	0.25860

Referred on three table from the series circuit results, the temperature reading is forming a uniform increase within 60 minutes and maintain around 15 to 20 minutes same as the parallel circuit since it is the same fire output. Then, same thing occurred where only the results on fire level 1 from Table 4.6 shows a uniform increase value of the voltage, current and power. As based on Table 4.7 and Table 4.8, the value of voltage and current shows almost similar with a slightly different even in different temperature same goes to the parallel circuit. It still shows that the different around 10˚C do not affect a lot to the value of voltage and current produced by the four peltiers.

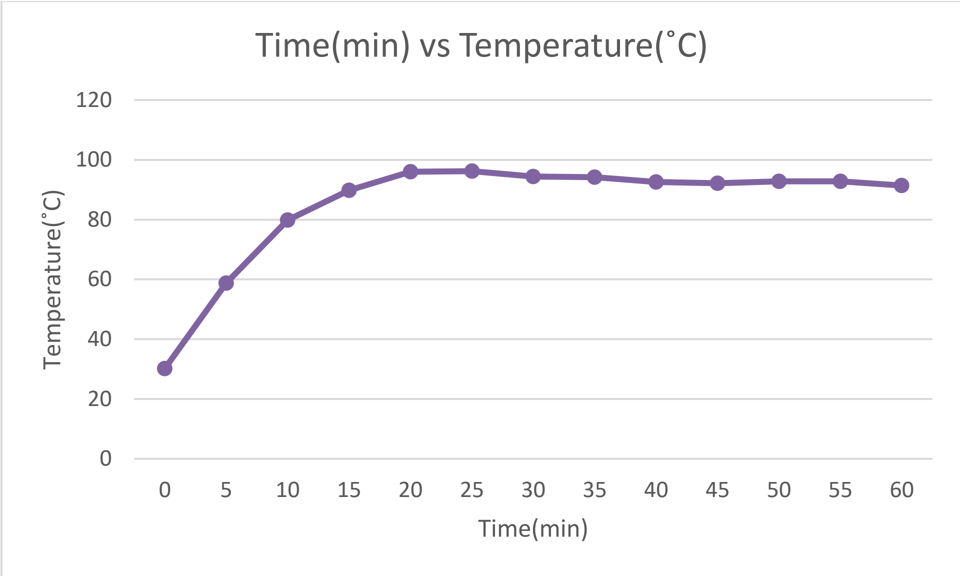

Figure 4-1: Graph of time against temperature for single peltier

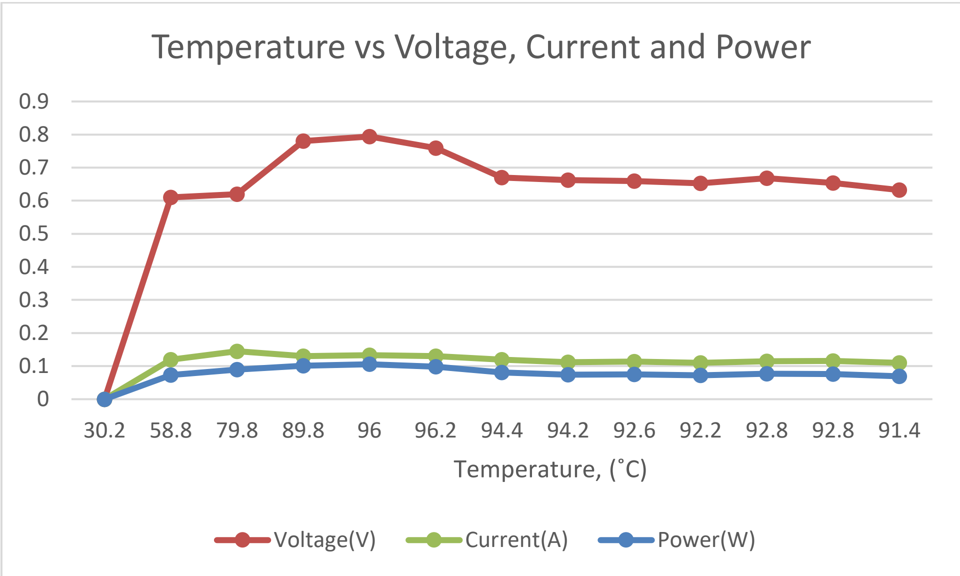

Figure 4-2: Graph of temperature against voltage, current and power for single peltier

Based on Figure 4.1, it shows that the temperature increases uniformly from the experiment start until minutes 15 and started to maintain from 20 minutes until 60 minutes. The temperature shows the maximum value at 20 minutes of the experiment. Then, Figure 4.2 shows that the maximum voltage value is at temperature of 96˚C and started to drop and maintain until the end of experiment. However, the value of current shows almost uniform reading after the maximum value of current at temperature 79.8˚C before it slightly drops. Maximum output of power was 0.10560W at the temperature of 96˚C.