**DESIGNING A COMBUSTION CHAMBER FOR CASCADING THERMOELECTRIC AND THERMOPHOTOVOLTAIC POWER SYSTEM**


By

**NUR MUHAIMIN AIDIL BIN MUHAIMI**

(Matrix no: 120407)

Supervisor:

**ENCIK KHAIRIL FAIZI MUSTAFA**


JUNE 2017

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfilment of the requirement to graduate with honors degrees in
**BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)**


School of Mechanical Engineering
Engineering Campus
Universiti Sains Malaysia

Title of thesis: **DESIGNING A COMBUSTION CHAMBER FOR CASCADING THERMOELECTRIC AND THERMOPHOTOVOLTAIC POWER SYSTEM**

Date of submission (Academic year): **7/6/2017 (2016/2017)**

Candidate Matrix no: **120407**

Name of supervisor: **Encik Khairil Faizi Mustafa**

## DECLARATION

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

Signed ………………………………………………………………………....
(Candidate)

Date ………………………………………………………………………………

**Statement 1**

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

Signed ………………………………………………………………………………
(Candidate)

Date ………………………………………………………………………………

**Statement 2**

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed ………………………………………………………………………………
(Candidate)

Date ………………………………………………………………………………

# Table of Contents

**LIST OF TABLES**

**TABLE OF FIGURES**

**NOMENCLATURE**

| | | |
|---|---|---|
| V | = | voltage |
| α | = | average Seeback coefficient |
| ΔT | = | temperature difference |
| σ | = | emissivity |
| T | = | temperature |
| 1 | = | thermocouple (bottom) |
| T2 | = | thermocouple (upper) |

## ABSTRAK

Kerja ini menumpukan pada rekaebentuk ruang pembakaran yang digunakan untuk melatakan sistem kuasa termoelektrik (TE) dan termofotovoltan (TPV). Oleh itu, rekabentuk hendaklah mengikut ciri-ciri sel-sel tersebut di mana kesesuaian kedudukan kedua-dua sel yang dipasang pada ruang pembakaran tersebut diperlukan. Salah satu ciri-ciri adalah berdasarkan bagaimana sel-sel itu berfungsi dalam menjana elektrik maka, bagi sel TPV iaitu menukarkan tenaga radiasi kepada tenaga elektrik dan sel TE pula menukarkan tenaga haba secara langsung kepada tenaga elektrik. Walau bagaimanapun, sel TE mempunyai kecekapan yang rendah dalam menjana kuasa elektrik berbanding sel TPV. Konsep rekabentuk dalam melatakan penjana kuasa sel TE dan sel TPV adalah di mana aliran haba yang dihasilkan oleh sel TPV itu dijadikan sebagai input pada sel TE tersebut. Gambaran rekabentuk ruang pembakaran ini apabila ruang pembakaran itu berbentuk silider yang menegak, sel-sel TE dan TPV dipasang secara kedudukan yang menegak di mana sel TE akan terletak di bahagian atas ruang tersebut dan sel TPV terletak di bahagian tengah ruang tersebut yang mana hamper pada sumber pembakaran. Di samping itu, ruang pembakaran ini menggunakan pembakaran media berliang (PMC) sebagai sumber pembakaran umtuk meningkatkan proses pembakaran. Tambahan pula, salah satu ciri-ciri yang terpenting bagi rekabentuk ini ialah aliran udara yang berpusar dalam ruang pembakaran tersebut. Penghasilan pusaran aliran udara ini sangat mencabar untuk difabrikasikan disebabkan oleh permukaan yang berlengkung akan tetapi keadaan ini boleh meningkatkan pemindahan haba dalam ruang pembakaran tersebut. Selain itu, plat TE direka di mana ketinggian plat tersebut boleh dilaraskan pada lima ketinggian yang berbeza untuk mendapatkan kedudukan yang terbaik bagi modul TE. Berdasarkan eksperimen yang telah dijalankan, bacaan suhu yang terhasil dalam ruang pembakaran menunjukkan rekabentuk tersebut diterima.

## ABSTRACT

This work focuses on the design of the combustion chamber which is used for cascading the thermoelectric (TE) and thermophotovoltaic (TPV) power system. Thus, the design is according to the characteristics of each of the cells itself where the suitable position of installation on both cells in the combustion chamber is needed. One of the important characteristic is due to how the cells is functioning to generate the electricity so, for TPV cell is converting the radiation energy into the electricity and TE cell convert the thermal energy directly into the electricity. However, TE cells have low efficiency for generate electric power than TPV cells. The development of concept of the design in cascading TE and TPV power generation is where the used heat stream or produced by the TPV is applied to the input of TE cells. The picture of the design as the combustion chamber in a vertical cylinder shape, the TE and TPV cells is installed in vertical sequence where the TE is on the top of the chamber and TPV cells at the middle of the chamber which is closer to the source. Besides, the combustion chamber use the porous media combustion (PMC) as the source of combustion to enhance the combustion process. Furthermore, one of the important characteristic of this design is the swirl flow of air in the combustion chamber. The tangential tunnel to the combustion chamber was designed to make the swirl flow. It is an enormous challenge to fabricate this part due to the curvy surface but it can enhance the heat transfer in the combustion chamber. In other hand, TE plate is designed to be an adjustable height with five difference height to have a good position for the TE modules. Based on the experiment, temperatures reading show the design is acceptable.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Research

Cascading Thermoelectric (TE) and Thermophotovoltaic (TPV) power system is meant that the TE and TPV generate electricity in the same place like combustion chamber. As we know, the TE is used to convert the thermal energy to the electric energy and the TPV is used to convert the irradiation energy to the electric energy. Logically, by cascading both the TE and TPV could generate high electricity compared to the stand-alone of TE or TPV. However, the aim of this project is to design the combustion chamber that can be used to cascade the TE and TPV. It is important to have a good result of electricity generated by both cells. Both cells of TE and TPV are installed on the same combustion chamber but in different position. Thus, the TPV cell should be installed at the region of radiation energy occurs in the chamber and TE cell should be installed at the waste heat energy releases from the combustion chamber. Generally, as the combustion chamber is cylindrically shape, the TPV cell should be installed at the middle of the chamber which is closer to the heat source and the TE cell is placed on the top of the chamber.

In the meantime, kerosene was used in this project as a fuel. Kerosene is a flammable liquid which is used in many industries and houses around the world as a fuel for light, heat and power. It is generally non-viscous and clear, however viscous substances such as wax and other thicker substances can be made from kerosene. It is also known as paraffin. It is an incredibly versatile fuel which can be used for a lot of applications. The advantages of using kerosene are low price of crude oil and available at any places. In general, kerosene is an important cooking fuel in India, especially, for the middle income urban locale who aspires for clean fuels but cannot afford Liquefied Petroleum Gas (LPG) due to its high cost and poor distribution network in some cases.

Furthermore, the porous medium combustion (PMC) is used in the combustion chamber. It is proved to be one of the feasible options to tackle the aforesaid problems to a remarkable extent in both technical and economic perspectives. As an internally self-organized process of heat recuperation, combustion in porous media differs significantly from the homogeneous flames. This difference is attributed to the following main factors: (1) the highly developed inner surface of the solid porous medium results in efficient heat transfer between the combustible medium and the inert solid; (2) dispersion of the reactant flowing through a porous media increases effective diffusion and heat transfer between the phases.

## 1.2 Problem Statement

Because the cascading TE and TPV power system has never been attempted, there are no fix design of combustion chamber by anyone yet. Thus, some information about designing a combustion chamber for cascading TE and TPV power system should be studied first.

Some of the other experiment has a complex set up which is use radiator to form the radiation energy. However, the radiator is too heavy and it is also too costly to purchase that we cannot afford to have it. Thus, a simple design is approached as long as the aim of the project is still the same which is to cascade the TE and TPV power system.

## 1.3 Scope of the Research

In order to accomplish the design of the combustion chamber, firstly, some useful information need to be studied as the design is acceptable to proceed the cascading TE and TPV power system. Then, mechanical drawing is used to design the combustion chamber before fabricate the design. Lastly, a simple experiment is done to observe the temperature profiles in the chamber.

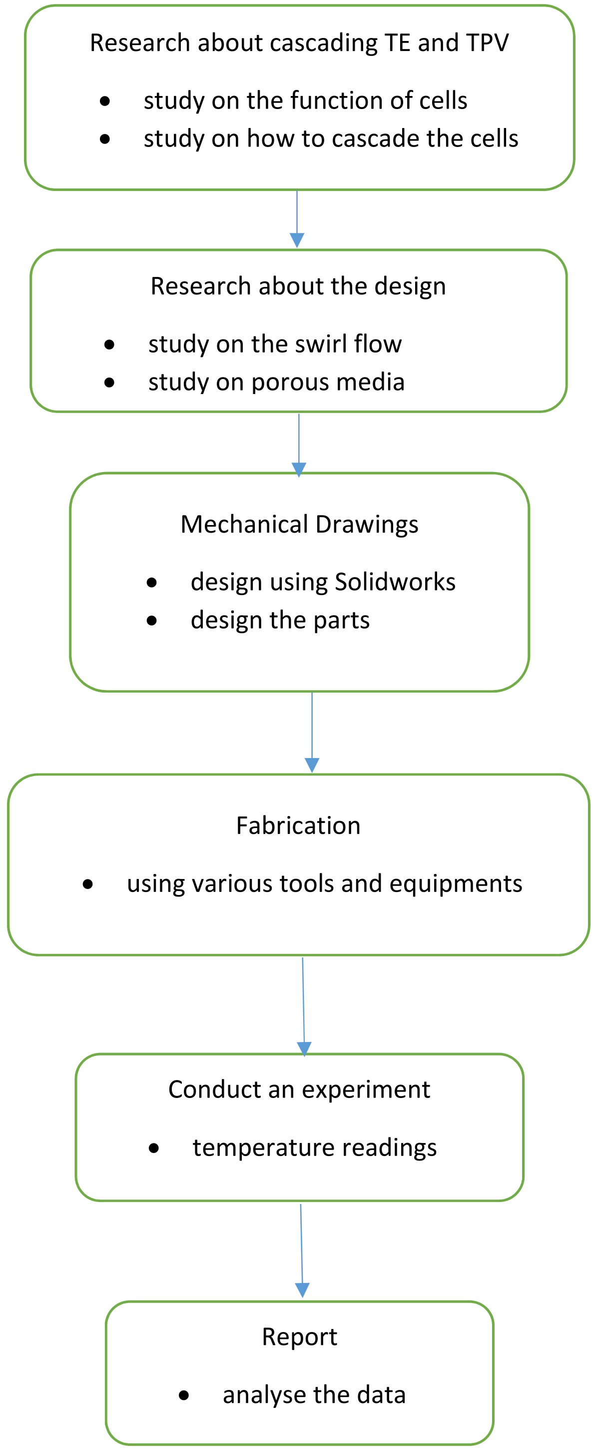


**Figure 1.1:** Flow chart of the implementation on designing combustion chamber

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Thermoelectric Converter

The potential utilization of thermoelectric technology is enormous and diversified, ranging from space applications to low-grade waste heat converter. There are also specific applications of thermoelectric devices reported in automobile exhaust system, military power supplies and self-powered heating system. Seeing that there would be exponential interest and relevancy as power generators, the First International Conference on Thermoelectrics (ICT) was held in Texas, USA in 1976. It has since become a major platform for researchers, scientists and academia worldwide for information exchange, collaboration and technology sharing. Since 1986, it is earmarked as an annual event and hosted its $34^{th}$ conference in Dresden, Germany in 2015.

The uniqueness of a thermoelectric devices lies on its ability to convert temperature difference into electrical energy. The fundamental concept was first discovered by a German physicist, Thomas Johann Seebeck in 1822. At first thought a thermoelectric power unit might be as simple as a bundle of thermocouples connected that will provide enough voltage to give a power output. However, the efficiency obtained will be extremely low and the thermoelectric devices must employ special materials and a complex fabrication.

The operation of the thermoelectric devices is based on the Seebeck effect, the Peltier effect, and the Thompson effect. According to the Seebeck effect, a voltage is produced in a circuit of two dissimilar materials if the two junctions are maintained at different temperatures. The Peltier effect was discovered by the French physicist J.C.A. Peltier in 1844. It states that if a current is passed through a circuit of dissimilar materials, one of the junctions will be heated and the other cooled. This is essentially a reversed Seebeck effect and it is also reversible. It means if the direction of the current flow is reversed, the junction that was formerly heated will be cooled and the formerly cooled junction will be heated. Peltier modules with their ability to heat and cool with great precision have proven useful in optical applications, automotive seats, and small consumer refrigerators. The Thompson effect was discovered in 1854 by the English physicist William Thompson. This effect fundamentally proved that there is a reversible absorption or liberation of heat in a homogeneous conductor when it is exposed to a simultaneous temperature and electrical gradients.

### 2.1.1 Principles of operation

When a body of thermoelectric material is maintained at a uniform temperature, the positive and negative electrical charges are uniformly distributed throughout the material. If one surface of the body, for example the end of a rod is heated, the charge distribution in the body is altered. The positively charged ions in the crystals remain fixed but the negatively charged ions tend to move to the cool end of the rod. The negative charges are carried by the free electrons. The heating effect causes an increase in the kinetic energy of these electrons and as a consequence they begin to move by diffusion toward the cooler end of the rod. The cumulative effect of this movement creates higher concentration of electrons at the cooler end of the rod. Consequently, a gradient of electrical charge is formed and a potential difference is established between the hot and cold ends of the rod. An electric current may then be allowed to flow in an external circuit or load.

In a thermoelectric device, semiconductor materials are commonly used to obtain respectable level of efficiency. The material most commonly used in these devices is lead telluride (PbTe) and germanium silicide (GeSi). These semiconductor materials are paired together to form the N-type semiconductor and the P-type semiconductor. PbTe has been successfully used by the National Aeronautics and Space Administration (NASA) as thermoelectric generators. New material classes could allow for waste heat recovery with better efficiency or use with high-temperature heat sources.

A typical arrangement of the N- and P-type semiconductor materials is shown in Figure 2.1. To generate a sufficiently high voltage in a thermoelectric power device, a number of semiconductors are arranged in an array that produces an additive voltage effect. The arrangement alternates the N- and P-type semiconductors. Multiple hot junctions and cold junctions are fabricated in joining the two types of semiconductors, and the terminal connections are made on the cold side of the array. The physical properties of PbTe and GeSi are tabulated in Table 2.1.

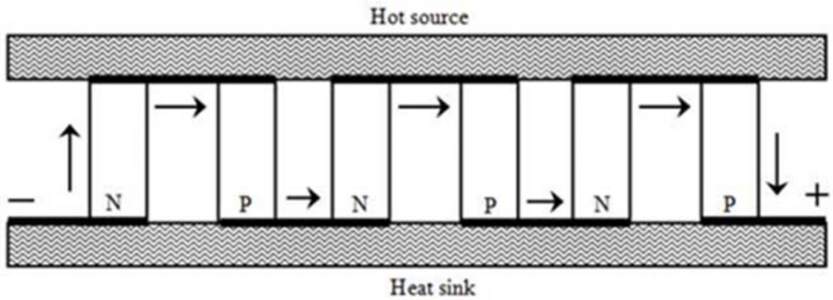


**Figure 2.1:** Arrangement of N and P junction in a thermoelectric

| Property | Lead telluride, PbTe | Germanium sillicide, GeSi |
|---|---|---|
| Temperature range, ΔT (°C) | 50–550 | 300–700 |
| Seebeck coefficient, α (μV/°C) | 218 | 230 |
| Resistivity, ρ (Ω.cm x $10^{-6}$) | 3.2 | 1.8 |
| Thermal conductivity, k (mW/°C.cm) | 14 | 49 |

**Table 2.1:** Typical values of physical properties for PbTe and GeSi

Accumulation of negatively charged electrons at the cooler end of the rod causes that end to be negatively charged with respect to the hot end. As a result, electrons flowing from the hot end of the rod are repelled or discharged at an increasing rate until equilibrium conditions are established. At this juncture, the electron flow from both ends of the rod will be equal. The cool end of the rod will still be maintained as negatively charged electrons with respect to the hot end. Characteristically, the lower the number of free electrons in a material, the greater will be the accumulation of electrons at the cool end of the rod and in turn, the higher will be the voltage generated for a specific temperature difference.

In thermoelectric cells, it is essential to observe that each thermoelectric material has an operating temperature range within which best performance is achieved. An upper limit on the operating temperature is reached when the material becomes "intrinsic". The intrinsic state happens when the heat input causes both positive and negative charges to occur in equal numbers, which reduces the magnitude of the output voltage generated. The approach to high temperature operation is the creation of a material that has the proper conductivity and does not become intrinsic. In general, most semiconductors become intrinsic when the operating temperatures reach about 1000$^{o}$C.

The open circuit voltage available from a junction is given by

$$V=\alpha\Delta T$$

where V is the voltage, α is the average Seebeck coefficient over temperature range used, and ΔT is the temperature difference between the hot and cold junctions.

### 2.1.2 Basic thermoelectric power generators

Figure 2.2 depicts a section of a semiconductor material arranged in contact with a heat source and a heat sink. The migration of the negative electrical charges is toward the cold end of the material. A good semiconductor material should have a low thermal conductivity. A temperature gradient is established in the semiconductor and unless the material has a low thermal conductivity, an excessively large fraction of the heat supplied would be wastefully conducted from the heat source directly to the heat sink. A low thermal conductivity for the semiconductor material thus contributes to an improvement in the energy conversion efficiency of the thermoelectric device.

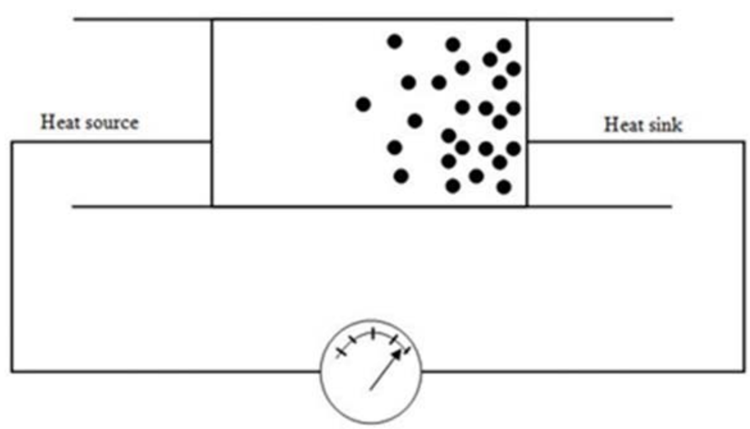


**Figure 2.2:** Electron concentration in electronic material

Thermoelectric generation is usually accomplished by means of thermoelectric couples. Small legs of P-type and N-type thermoelectric elements are connected in series and then sandwiched between insulating ceramic substrates. These couples are most often arranged into a planar package called a thermoelectric module. Thermoelectric generator (TEG) systems are composed of these modules along with additional equipment that moves heat and electricity through the system. Because thermoelectric efficiency increases with the temperature difference, recent advances in high-temperature TE modules are showing promise. Demonstrations of high-power TE waste heat recovery has typically been less than 1 kW, with notable demonstration of 169 W output at cement kiln. A 250 W generation of gas furnace exhaust and 240 W generations from a steel furnace have also been accomplished.

## 2.2 Thermophotovoltaic

This section defines the thermophotovoltaic (TPV) energy conversion process and TPV applications.

### 2.2.1 TPV energy conversion

Similar to all energy conversion concepts, TPV conversion is a method for converting thermal energy to electrical energy. The concept is illustrated in Figure 2.3. Thermal energy from any of the thermal sources is supplied to an emitter. Radiation from the emitter is directed to photovoltaic (PV) cell where the radiation is converted to electrical energy. TPV converts heat directly into electricity and has been examined in all major resources. At the current stage of research, high efficiencies have not been demonstrated and it is uncertain which practical efficiencies TPV system can achieve. However, even moderate (partly) demonstrated efficiencies make TPV conversion already attractive for the efficient use of fossil fuels. Currently, TPV systems are mainly developed for fossil fuel powered combustion applications.

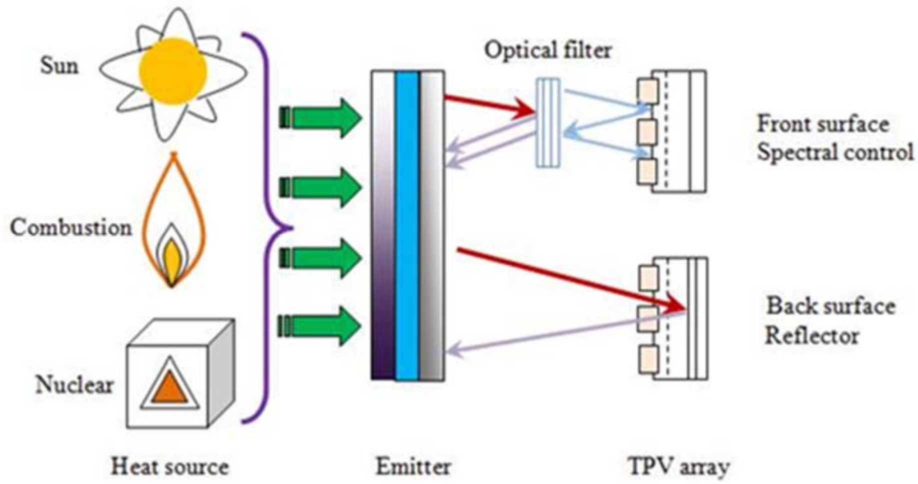


**Figure 2.3:** TPV energy conversion concept

The early TPV research in the 1960s and 1970s was confined to using either silicon ($E_g$ = 1.12 eV) or germanium ($E_g$ = 1.12 eV) PV cells. Silicon requires a large emitter temperature ($T_e$ ≈ 2000 K) for an efficient TPV system, and Ge cells were of low efficiency. However, in the 1980s new efficient PV cell materials such as gallium antimonide (GaSb, $E_g$ = 0.72 eV) and indium gallium antimonide (InGaAs, where 0.36 ≤ $E_g$ ≤ 1.42 eV) became available. In addition, new selective emitters and filters that can produce the bandgap matched radiation were being developed. As a result, a resurgence of interest in the TPV power conversion began in the late 1980s

### 2.2.2 Technology aspect

TPV conversion has inherently some technological properties which makes it advantageous compared with existing routes to supply electricity. In industrial countries the vast amount of electricity is centrally generated in large power plants using internal and external heat engines. The electricity is transmitted and distributed via the grid. One major disadvantages of central power generation is the waste of large amounts of heat. Even modern fossil fuel powered combined cycle power plants discharge about half of their input as waste heat. Other disadvantages include system complexity, security of supply issues and distribution losses. Renewable power generation systems (e.g. solar photovoltaics and wind) can replace large power plants. However, their widespread use requires economic high power and high capacity electrical storage systems that have not been identified yet.

On the small-scale power range, in order of milliwatts to hundreds of watts, a large amount of non-grid connected electricity originates from (rechargeable) batteries, which have disadvantages in terms of lifetime, slow charging process, and a low gravimetric energy density (MJ/kg). Hydrocarbon fuels have in the order of 100 time higher gravimetric energy densities and can be easily stored and quickly supplied. Even a low efficient TPV system could have superior properties compared with batteries. Hence, TPV conversion is a promising technology to convert hydrocarbon fuels into electricity. In this way, a lightweight and quickly rechargeable portable power generator could be realized. TPV conversion is one of several other technologies in a research and development stage that offer advantages over the existing electricity supply infrastructure. This is especially true for the intermediate power range, around 10 W to 10 kW. The advantages include high reliability, low noise, high gravimetric and volumetric energy density, portability and long operation time.

### 2.2.3 Basic principle

TPV conversion uses a variety of heat sources to heat up a radiator (also named as emitter) to temperatures of 1300-2000 K (~1000ºC-1730ºC). This temperature range leads to a theoretical hemispherical total radiation per unit area of approximately 16-91 $W/cm^2$ according to the Stefan-Boltzmann law with emissivity of one ($\sigma T^4$). The major part of this radiation is in the infrared spectral range according to Planck's radiation law. Ideally no radiation is lost due to the close arrangement of radiator and PV cells. TPV systems operate steadily in terms of intensity, spectrum and angle of radiation as well as PV cell temperatures. In waste heat recovery applications, these systems could operate steadily 24 h a day and 365 days per year.

TPV system design usually requires a spectral control concept, as well as selection and design of the heat source, radiator, and PV cell. Spectral control is a method to spectrally match the absorbed power of the PV cell in accordance to the cell bandgap. Alternatively, the spectrum can be spectrally controlled by a selective radiator and by filters and mirrors within the PV cell. TPV systems can suppress or recover the photons lost by some form of spectral control to increase the efficiency. This spectral control option potentially leads to higher efficiency of TPV conversion compared with solar PV conversion.

### 2.2.4 Application

Besides the development of new PV cell and emitter technology, the many applications for TPV energy conversion are also the driving force in the resurgence of TPV interest. The simplicity and potential high efficiency of TPV conversion are the two attractive features that lead to many potential applications. Since TPV is a direct energy conversion process, the only moving parts in the system are fans or pumps that may be used for cooling the PV cells. The components of the system are the thermal source, the emitter (and possibly a filter), the PV cells, and the waste heat rejection system. Each of these components is in the solid state with only the P cells and possibly the filter being a somewhat complex solid state device. In addition to the simplicity and potential high conversion efficiency, TPV can be easily coupled to any thermal source.

A TPV system powered by radioisotope decay (RTPV) is a potential power system for deep space missions where the solar radiation energy is too low for a conventional PV power system to be used. The first radioisotope power system used thermoelectric energy converters (RTG). Combustion-driven TPV has many potential commercial applications. For natural gas-fired appliances such as furnaces and hot water tanks, TPV can be added for the cogeneration of electricity. In such applications, attaining high TPV efficiency is not essential since the waste heat for the TPV conversion process is completely utilized. Portable power supplies for both commercial and military use is another important combustion TPV application. An important TPV advantage over existing internal combustion-driven applications is quiet operation. This is especially true in military missions that require the mission to be undetected. Another combustion-driven TPV application with commercial potential is the power supply for hybrid electric vehicles. In such an application the TPV system is sized to provide enough power for operation at cruise speed and battery charging. For acceleration power the battery is used. One important advantage of all TPV applications is that they are environmentally benign. The TPV system is nearly silent and emits no pollutants. This is obvious in the case of solar driven system. For a nuclear powered system there are no combustion products; however, care must be taken to ensure that no radioactive material is released.

### 2.2.5 Energy balance

The energy flow in a general type of TPV system is shown in Figure 2.4. The total input, $P_{input}$ depends on the heat source and originates from various sources. Four heat sources are commonly found, namely chemical energy (e.g. hydrocarbon combustion), nuclear energy (e.g. radioisotope heat), solar energy and waste heat (e.g. from industrial high-temperature processes). In a radioisotope, solar, and waste heat recovery the total input may be defined as a heat flux (W/cm2). For solar TPV, the optical efficiency of the concentrator can be defined as the heat source efficiency. In a hydrocarbon combustion system the total input may be defined by the fuel flow rate and the calorific value of the fuel. The efficiency of a TPV system is defined as

$$\eta_{TPV} = P_{elec} / P_{input}$$

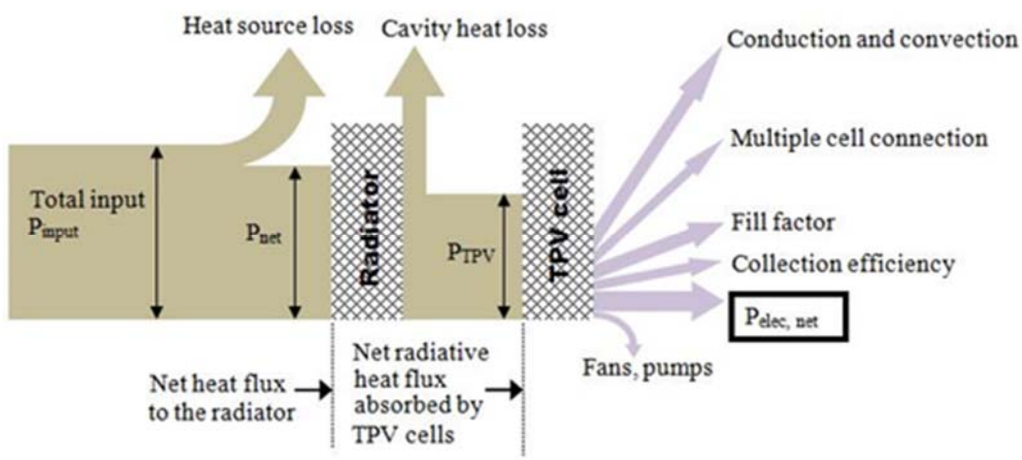


**Figure 2.4:** Sankey diagram of a general type of a TPV system The Thickness of each energy flow path is not proportional in size

### 2.3 Development of cascading Thermoelectric (TE) and Thermophotovoltaic (TPV)

Development of cascading TE and TPV is related to the design of combustion chamber itself. The formation of radiation energy and thermal energy must be considered into the design as the TE and TPV could convert the energies into electrical energy. Thus, some people are using radiator in their experiment setup to form the radiation energy so that the TPV cell can convert the radiotion energy to the electric energy. However, the radiation energy can be produced by porous media combustion (PMC) as shown in Figure 2.5. It is relatively a new concept where the entire combustion takes place in a radiatively participating due to high surface area. Besides, high surface area of the porous material results in efficient convective heat transfer between the solid and fuel, and this makes the reaction zone to extend with a uniform temperature profile across the burner.

**Figure 2.5:** Porous Media (PM)

## 2.2 Swirl Flow of Air

Swirling flow has received considerable attention because of its relevance to industrial applications such as flame stabilization in gas turbines and in pulverized coal furnaces, and enhancement of combustion in piston engines. When the inflow swirl level is higher than a critical value a flow reversal can be formed in the flow field, a phenomenon known as vortex breakdown. Swirl motion is shown to increase turbulence generation in piston engines, excessive swirl can trigger large scale unsteady motion, which may lead to acoustic and structural oscillations in combustion chambers causing serious problems for the combustor operation. Besides, decaying swirl flow induced by tangential feed nozzle has been used (as shown in Figure 2.6) to enhance the rate of heat and liquid – solid mass transfer at the walls of the tubes and to improve the performance of equipment. Heat and mass transfer under swirl flow were concerned with the wall of the tube or the annulus along which swirl flow is advancing, no work has been reported on the effect of swirl flow on the rate of heat or mass transfer at a surface perpendicular to the direction of swirl flow e.g. the bottom of the cylindrical container in the inlet zone despite the technical importance of the subject. Furthermore, contrary to flow at vertical cylinders where swirl flow is more efficient than axial flow in enhancing heat and mass transfer.

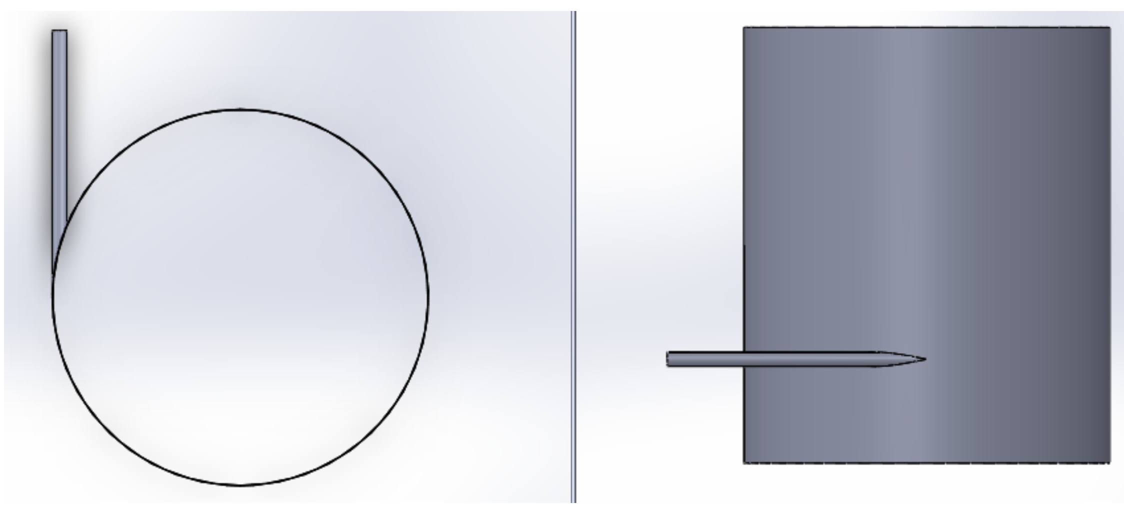

**Figure 2.6:** Tangential feed nozzle for swirl flow

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Introduction

The main aim of this project is to design the combustion chamber that can be used to cascade both the TE and TPV. Firstly, some useful information is studied before designing the combustion chamber for various parts. Then, mechanical drawing was constructed to provide the design of the chamber and the most important thing is to have a good dimension before proceed to the fabrication. After that, the material used in the design was chosen as a suitable medium for combustion chamber that can withstand high temperature. Next, the design is fabricated based on the draft in mechanical drawings. Lastly, a simple Design of Experiment (DOE) is conducted to observe the temperature produced in the combustion chamber by controlling the pressure of air intake by regulator.

## 3.2 Raw Material

The material used in designing the combustion chamber was mild steel. It is because mild steel has high melting point which is about 1510 °C so that the combustion chamber can attain high temperature as the TE and TPV could generate the electricity.

## 3.3 Mechanical Drawings

Solidworks is one of the mechanical drawing that is used in designing for this project. There are parts that have been designed by using Solidworks with dimensions before fabricate the design.

### 3.3.1 Combustion Chamber

The combustion chamber is the main body to be designed where the combustion is take place and this is the part for cascading TE and TPV cells power generation. Besides, the existence of tangential pipe at the bottom of the combustion chamber allows the swirl flow of air in the combustion chamber as shown in the Figure 3.1. The dimensions of the combustion chamber and tangential pipe as in the Table 3.1.

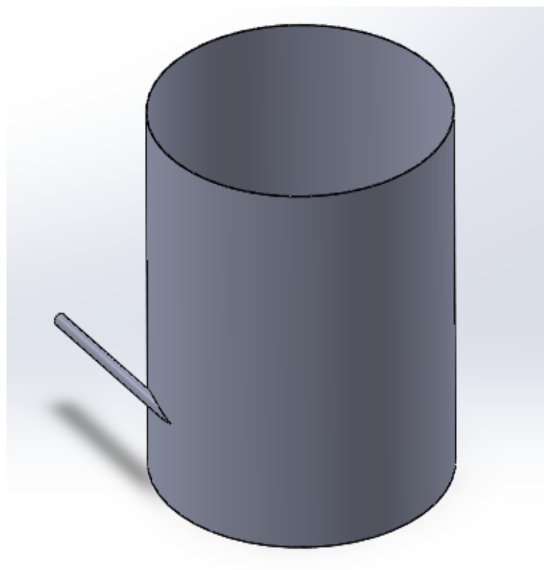

**Figure 3.1:** Chamber with tangential tunnel

| Parts | Combustion Chamber | Tangential Pipe |
|---|---|---|
| **Diameter** | 25.3 cm | 1.0 cm |
| **Height** | 30.2 cm | - |
| **Length** | - | 18.0 cm<br>(from the center of chamber) |
| **Thickness** | 0.5 mm | 1.0 mm |

**Table 3.1:** Dimensions of combustion chamber and the tangential pipe