THERMOELECTRIC POWER SYSTEM FROM A LIQUID-FUELED COMBUSTOR

By:

MUHAMMAD SAFUAN BIN RAZALI

(Matrix no.: 126961)

Supervisor:

Mr. Khairil Faizi Mustafa

June 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honors degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

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………………………………………………………... (Muhammad Safuan Bin Razali)

Date………………………………………………………...

STATEMENT 1

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.

Signed………………………………………………………... (Muhammad Safuan Bin Razali)

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………………………………………………………... (Muhammad Safuan Bin Razali)

Date………………………………………………………...

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful. First of all, all praise to the Almighty One, Allah for giving me the opportunity to live in this world and giving me a good health that I capable of doing my daily task peacefully. *Alhamdulillah*.

I would like to owe my deepest gratitude and appreciation to Universiti Sains Malaysia and its management for giving me the chance to complete this four-year course in Mechanical Engineering.

I would like to express my gratitude to the dedicated supervisor, Mr. Khairil Faizi Mustafa, who has given me the chance to carry out this interesting and yet challenging project. Besides, thanks for giving constant guidance and advice throughout this whole project. It would not be possible for the projects to proceed this far without your patience and enthusiasm encouragement.

Not to be forgotten, I would like to extend my gratitude to the staffs of the School of Mechanical Engineering for always give the fullest support. They always more helpful to assist me and provide guidance regarding the machines, processes and materials. Apart from that, I would like to thank all my fellow friends who provide me the encouragement and assistant whenever needed.

Last but not least, I would like to thank my dearest family and friends for their continuous support along the journey of completion of this project. To those who have contributed directly and indirectly, thank you very much. Without the continuous help, I wouldn’t able to reach this far.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Symbol	**Description**
TE	Thermoelectric
TEGs	Thermoelectric Generators
EM	Electromagnetic
NIR	Near-Infrared
SWIR	Short-Wavelength Infrared
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NO_2	Nitrogen Oxides
GaSb	Gallium Antimonide

SISTEM KUASA TERMOELEKTRIK DARI PEMBAKAR CECAIR BAHAN API

Abstrak

Tujuan projek ini adalah untuk mereka bentuk pembakar supaya dapat menghasilkan tenaga elektrik daripada sel termoelektrik. Sifat-sifat pembakaran dan prestasi pembakar untuk penghasilan kuasa termoelektrik akan dinilai juga. Kerja eksperimen yang melibatkan penghasilan suatu haba daripada pembakaran cecair bahan api untuk menghasilkan tenaga elektrik melalui sel termoelektrik. Julat operasi pembakar telah diubah untuk menampung daripada kawasan yang kekurangan bahan api kepada kawasan yang kaya dengan bahan api. Tenaga elektrik yang dihasilkan telah diukur dengan menggunakan multimeter. Ia didapati bahawa kuasa yang dihasilkan adalah berkadar terus kepada arus (seperti dinyatakan di dalam data untuk $n = 1$, $P = 0.00975$ W dan $I = 0.010$ A, $n = 2$, $P = 0.01182$ W dan $I = 0.012$ A, $n = 3$, $P = 0.02140$ W dan $I = 0.020$ A) dan kuasa juga adalah berkadar terus kepada voltan (seperti dinyatakan di dalam data untuk $n = 1$, $P = 0.00975$ W dan $V = 0.975$ V, $n = 2$, $P = 0.01182$ W dan $V = 0.985$ V, $n = 3$, $P = 0.02140$ W dan $V = 1.078$ V). Secara kesimpulan, sifat-sifat pembakaran dan prestasi untuk penghasilan kuasa termoelektrik oleh pembakar telah dapat dinilai daripada eksperimen ini. Pembakar telah berjaya direkabentuk.

THERMOELECTRIC POWER SYSTEM FROM A LIQUID-FUELED COMBUSTOR

Abstract

The aim of this project is to design a combustor to generate electricity from the thermoelectric (TE) cells. The combustion and performance characteristics of the combustor for TE power generation is also evaluated. The experimental work involved the direct generation of heat from the combustion of liquid fuel to generate electricity via the thermoelectric cells. The operating range of the combustor was varied to cover from the fuel-lean to the fuel-rich region. The electricity generated was measured using a multimeter. It was found that power generated is directly proportional to the current (as in data for $n = 1$, $P = 0.00975$ W and $I = 0.010$ A, $n = 2$, $P = 0.01182$ W and $I = 0.012$ A, $n = 3$, $P = 0.02140$ W and $I = 0.020$ A) and power is also directly proportional to the voltage (as in data for $n = 1$, $P = 0.00975$ W and $V = 0.975$ V, $n = 2$, $P = 0.01182$ W and $V = 0.985$ V, $n = 3$, $P = 0.02140$ W and $V = 1.078$ V). In conclusion, the performance and combustion characteristics of thermoelectric power generated by combustor were evaluated in this experiment. The combustor was successfully designed.

CHAPTER 1 INTRODUCTION

1.1 Research background

For the test experiment, I put thermoelectric on top of the chamber to observe the electricity generation from the heat flux directly to electrical energy through a phenomenon called Seebeck. The operation is based on the gravity-fed liquid fuel combustion to a stack of thermoelectric cells to produce the power. The combustion process includes various fuel-air mixing process. The specific effects of the fuel-air ratio on the thermal, combustion, and electrical characteristics of the TE systems.

With rapid expansion and development of technology, the society rapidly reached a point of over consumption of any kind of natural resources. The facts that these resources are exhaustible, and our utilization rate is high, lead to the concern that in a very near future the fossil fuels will run out.

The concerns about energy first surfaced during the energy crisis of the seventies of the past century. This leads to development of nuclear and solar energy. As can be seen in Figure 1, fossil fuels still account for over 3/4th of the world's total energy supply today (Mtoe in Y axis label means million tonnes of oil per year) [1]. Although nuclear and solar energy may provide more promise for the future, fossil fuel cannot be quickly replaced for all applications, at least in the near future because of their several advantages including non-radioactivity, safety, matured utilization technologies, high conversion efficiency and cost.

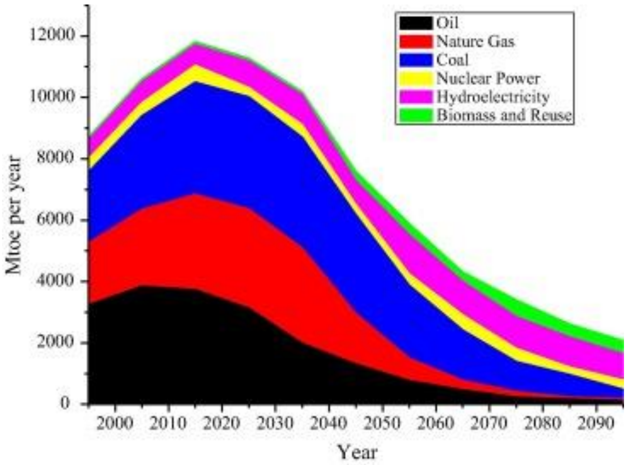


Figure 1: Global energy consumption by source in 2012 and in future [1].

However, when one considers the negative impact of fossil fuels, besides the limited reserves, concerns over environmental issues is regarded as serious. In 1992, the United Nation Conference on Environment and Development provided global efforts to protect our environment. Then, at the Kyoto protocol in 1997, many developed countries discussed the possibility and requirement of reducing the actual carbon emissions by 7% below the 90s level over the next 10 years [2]. During the last century, more attention was given to the utilization of fossil fuels. Indeed, many problems are directly related to their consumption as fuel, and the pollutant, such as CO, CO_2, hydrocarbon, soot and NOx, that they produce during their combustion [3].

The impact of the emissions, such as NOx, CO and UHC on the environment is critical now. Thermodynamic improvement of combustion efficiency and power output suggests the higher flame temperature. However, the long residence time of molecular nitrogen at peak temperature zone with high availability of oxygen (for few seconds above 1800 K or for only milliseconds above 2300 K) will lead to the formation of NOx. They are formed from the oxidation of the free nitrogen in the combustion air or fuel, and are called “thermal NOx.” They are mainly a function of the stoichiometric adiabatic flame temperature of the fuel, which is the temperature reached by burning a theoretically correct mixture of fuel and air in an insulated vessel.

In 1971, an interesting phenomenon was observed at high furnace temperature above auto ignition temperature of the mixture, that with exhaust gas recirculation, no flame could be seen and no UV-signal could be detected. Despite that, the combustion was stable and smooth, the fuel was burnt completely and the NOx emissions were close to zero. Its acronyms are usually related to the inlet air, such as: Excess Enthalpy Combustion (EEC), High Temperature Air Combustion (HiTAC) in Japan, or Moderate and Intense Low Oxygen Diffusion (MILD) Combustion in Italy, Colorless Distributed Combustion (CDC) and Low NOx Injection (LNI) in the USA. No matter how it is called, it implies hot oxidizers with exhaust gas recirculation at high turbulence level, and under typical conditions, it occurs with no flame, very lean and stable. The greenhouse exhaust emissions created by aircraft engines are directly emitted into the stratosphere, the ozone layer can be greatly destroyed and the global warming problem will arise. [4]

A new combustion technology is needed to meet the demands of higher pressure, leaner fuel combustion while meeting increasingly more stricts emission standards. So far many topics have been reviewed to understand how modern technologies are changing the way in which these engines operate. Since most of the aircraft engines and industrial combustors are operated with liquid fuels is limited with only few on-going laboratory works, it is important to review the combustion with liquid fuels. Such review should help to understand the role of combustion on the improvement of performance.

The technical review report presented here will first discuss major technical and physical challenges in combustion. Secondly, review of studies on combustion of selective liquid fuels will be presented. Thereafter, the authors will also discuss some basic research areas in combustion application in thermoelectric that need improvement. The discussion will focus on future directions, combustion, and thermoelectric.

1.2 Problem statements

1) It was high fuel consumption of the combustor when to run the experiment.

2) The overall efficiency thermal measurements are generally unknown because the greater emphasis is placed on the practicality.

3) The emission from the fuel combustion exposed to the environment is generally ignored resulting in severe health hazards issues to the user and people surrounding.

1.3 Objectives

1) To design a combustor to generate electricity from the thermoelectric cells.

2) To determine the combustion and performance characteristics of the combustor for thermoelectric power generation.

1.4 Scope and limitations of the study

This project involves the development of a combustor to be used as a power generation unit using TE cells. The design of the combustor is based on the combustion of liquid fuel as a primary fuel source and the heat generated from the combustor will be used to capture the heat. Given that the heat generated in the combustor is generally exhausted to the environment, the TE cells will be placed on top of the combustor. The temperature profile of the combustion is determined by virtue of measuring the temperature across the combustor. The performance characteristics of the system is elaborated by determining the electricity generated from the TE cell.

Firstly, I design of a combustor based on design calculations. Then, I design of a suitable heat that can be used for measured voltage and current values by using multimeter. I characterize the power system based on experimental work. The combustor used in this study can preferably use fuel for combustion process. Then, the power value of the heat produced can determined based on the formula P = V x I.

CHAPTER 2 LITERATURE REVIEW

2.1 State of the combustion with liquid fuel

Preheating of combustion air with high temperature exhaust recirculation and high-speed injections of air and fuel are the main requirements for achieving the combustion. Strong entrainment of high-temperature exhaust gases, diluting fuel and air jets, is the key to maintaining the combustion. Essential environment conditions for the establishment of the combustion are: local oxygen concentration < 5-10%, and local temperature > the fuel self-ignition temperature in the reaction zone. Such conditions can be achieved by high dilution of the reactants with the flue gas (N2 and CO2-rich exhaust gas). In comparison with conventional combustion, the thermal efficiency of the combustion can be increased by more than 30% but the NOx emission can be reduced by more than 70%, when a regenerator is used to recycle the waste heat of flue gases [5].

The combustion has been extensively investigated for systems using gaseous fuels such as hydrogen, methane and ethanol. However, to the best of the authors' knowledge, there is no pilot scale or large-scale investigation of the combustion using liquid fuels although liquid fuels are essential to gas turbines. Therefore, it becomes imperative to understand the characteristics of the combustion with liquid fuels to increase the engine efficiency and reduce NOx and CO emissions. In the following sections of this contribution, the focus is on reviewing the available work on the combustion with liquid fuels.

2.2 Diesel

Torresi et al. [7] designed an aerodynamic ally staged swirled burner using the diesel as the fuel. The burner has been experimentally tested and numerically simulated under diluted and highly preheated inlet flow conditions. The staged injection is realized through a double coaxial air inlet with the same swirl orientation. The diesel is injected through a central atomizing nozzle characterized by very high range ability. The air was heated to 673 K and diluted by CO_2 and H_2O, and the concentration of O_2 is 12.59%. It may be noted that there is no information about the diesel atomization and evaporation. The numerical simulation was in a good agreement with experimental results, confirming that the burner, under properly operating conditions, is able to burn the fuel completely without a flame front and with a very uniform temperature field, as seen in Figure 2.

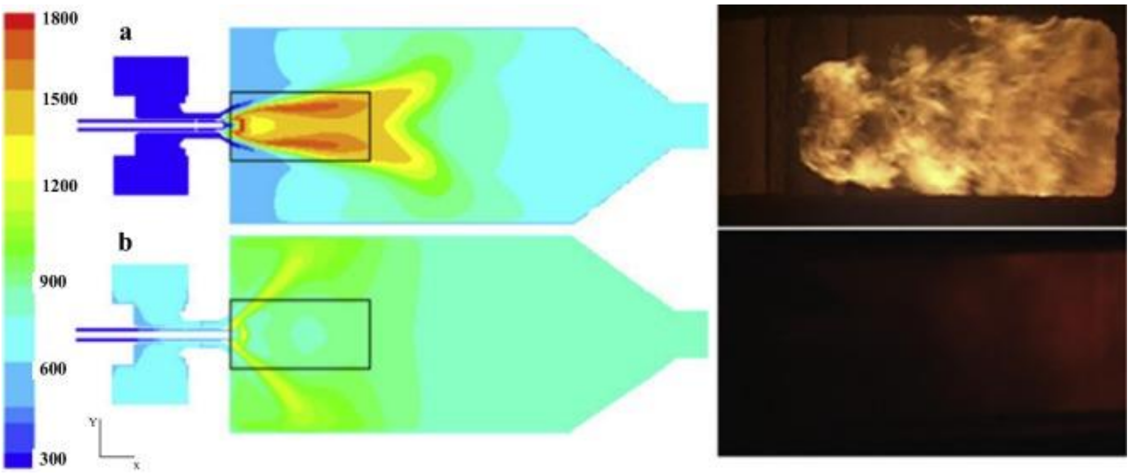


Figure 2: Contours of temperature for flame (a) and flameless (b) conditions with the relative experimental images [7].

In China, Professor Lin's research team also realized the flameless combustion of liquid diesel in 2012 [8,9]. After Li et al. [3] firstly pointed out that flameless combustion occurred not only in high temperature low oxidant concentration but also in high temperature high oxidant concentration, Lin [8,9] also believes that air preheating is not an essential condition to attain flameless mode and that the air injection speed is more important to lower the whole reaction rate.

A cubical combustor was designed with a recirculation structure, as shown in Figure 3, and flameless combustion experiments were carried out by using 0# diesel. It has been observed that with the increase of the injection momentum of the reactants, the combustion mode is converted from flame to flameless while the recirculation structure does not change. The liquid diesel was supplied by air blast atomizer, however, the performance of the atomizer was not mentioned. It can be concluded from the analysis in the works [8,9] that the air injection velocity and the entrainment and mixing with the high temperature exhaust gas are considered as the most important factors in controlling the reaction rate and changing the combustion mode, and that the appropriate preheating of the combustion air is an effective way to enhance the combustion stability. The effect of the high temperature was not emphasized, which would reduce the cost of the experiment remarkably. Otherwise, the conclusions are very important and useful.

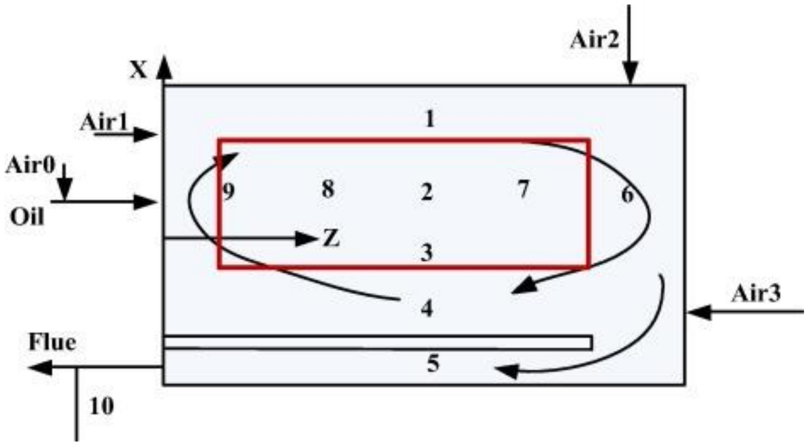


Figure 3: Combustor configuration and thermocouples layout [8].

2.3 Kerosene

Since kerosene is a complex mixture of hydrocarbons, effort has been made to achieve the combustion using liquid kerosene after several attempts on achieving the combustion with the liquid hydrocarbons [4–13].

Experimental and numerical research has been carried out to use a two-stage combustor to investigate characteristics of the combustion with kerosene. The design of the combustor is based on the injection of fuel and air at ambient conditions, as seen in Figure 4. The fuel injection and air injection schemes are believed to have an impact on fuel spray, increasing shear force and resulting in enhancing mixing and evaporation of droplets. The latest research published in 2014 [15] shows that the two-stage combustor was not ideal for establishing the combustion. Therefore, a swirl-based combustor with a chamfer at the top of the combustor (see Figure 4b) was considered, aiming at improving the droplet residence times and the recirculation rate. Observations from this study are summarized [15]. Firstly, the combustion was stabilized in the base combustor. However, for higher fuel flow rates combustion was not achieved and unburned fuel accumulated in the combustor. Secondly, a chamfer near the exit in the modified combustor configuration helped increase the circulation rate and residence time. The outstanding performance of the burner with very low chemical and acoustic emissions at high heat release rates indicates the potential for various industrial applications.

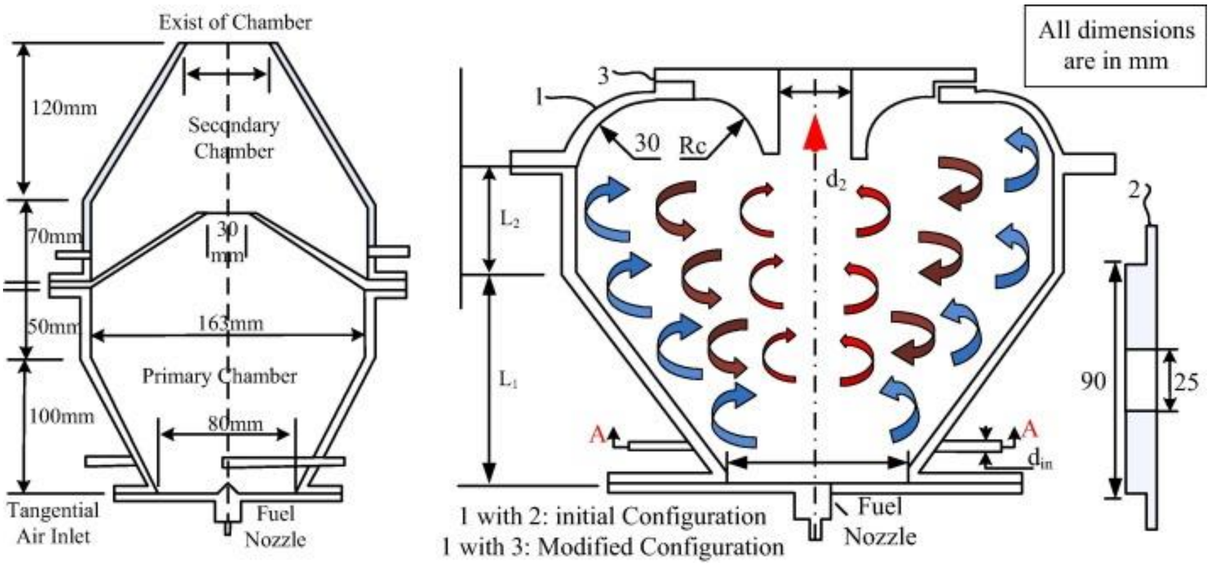


Figure 4: Schematic diagrams of the combustors: two stage combustor [4,13] and swirl based combustor [15].

Simulation and experimental research on the combustor based on trapped-vortex [16,17] were also carried out with kerosene. The zero dimensional and three dimensional numerical simulations was performed first. The emissions and temperature profile of the outlet are in good agreements with the cavity configuration. In the experimental work, the emphasis was to analyze the influences of the inlet air temperature, air flow-rate and equivalent ratio. The fuel is supplied by air atomization injectors, when the inlet temperature is above 550 K, and the reference velocity is higher than 10 m/s. The authors considered that the combustion was stabilized by the trapped vortex. But the simulation results were not validated by the experiments (see Figure 5).

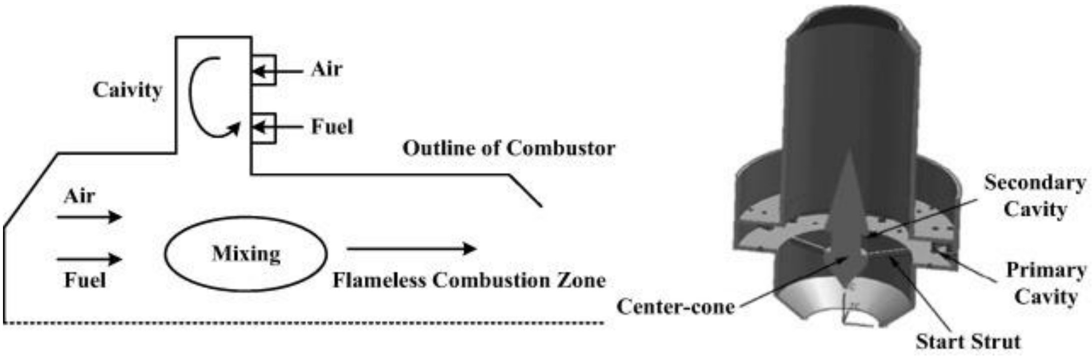


Figure 5: Schematic diagram of the combustor [16,17].

2.4 Other liquid hydrocarbons

To avoid the complex mixture of real liquid hydrocarbon fuels, surrogate fuels are commonly used with two purposes, for designing better reproducible experimental tests, and for obtaining physical insights from well-controlled fundamental and kinetic studies. Since 2006, Gutmark's research team has been focusing on the combustion and the use of gas fuel [8–12]. In 2009, they published a paper about the combustion with several kinds of liquid hydrocarbons [17].

In a collaborative work between Goodrich Aerospace and the University of Cincinnati, a burner was designed and tested [8]. In the first design, the burner was composed of a circle of premixed air/fuel jets directed to mix with the combustion products. The results were globally unsuccessful [8,9]. The burner demonstrated the usual premixed flame instabilities when combustion transits out of steady mode. They found that it is a key factor to achieve the necessarily high turbulence intensity for the model.

So after this, researchers from Goodrich Aerospace and the University of Cincinnati modified the design of combustor to gain a stronger recirculation zone and to operate at the conditions typical as shown in Figure 6. In particular, the emphasis was placed on achieving high mixing rate while maintaining a low pressure drop across the fuel injection. A low-noise high-sensitivity microphone and thermocouples were used to determine temperature uniformity of the model.

The research work has shown that operating the burner at high oxidizer temperature (from 325 °C to 525 °C) and relatively low pressure drop (from 3% to 5%) allows the combustion to occur while running very lean (equivalence ratio is from 0.7 to near LBO). Different fuels including propane (liquid), n-butane (liquid), n-pentane, n-hexane, toluene, jet-A and a blend of alkanes/alkenes centered on C9 were tested. All the fuels, with the exception of n-butane, showed very similar characteristics [13]. According to the conclusion of the research, we must take care in designing the compact of combustor for aerospace application. High turbulence and fast mixing would tend to produce greater magnitudes of acoustical pressure oscillations, this level of thermo-acoustic stability might cause the fluid and combustion instabilities.

Derudi et al. [18] from Italy also focused on the investigation of the sustainability of the combustion for liquid hydrocarbons using a dual-nozzle laboratory-scale burner. Air and gaseous fuel are fed through the bottom of the combustion chamber, as shown in Figure 6a.

After finding that configuration is not suitable for liquid fuels, the apparatus has been modified by implementing the double-nozzle (DN) inlet configuration as shown in Figure 6c, where the preheated air enters the combustion chamber through the bottom nozzle, while the liquid fuel is injected as a well-dispersed and homogeneous spray through a water-cooled plain jet airblast atomizer. The two jets interact perpendicularly and mix with each other in a high turbulence region. The research has shown that the DN configuration allows to sustain the combustion by directly injecting different liquid hydrocarbons under the conditions that are previously established using a gaseous fuel as shown in Figure 6b. DN configuration provides different results for liquid hydrocarbons, suggesting that the combustion characteristics are probably more influenced by the physical state of fuels than the chain length of the hydrocarbon. For example, the combustion region in terms of the window Tavg (average combustion chamber temperature) −Kv (gas recirculation rate) space was found enlarged with the liquid hydrocarbons in comparison with the gaseous ones.

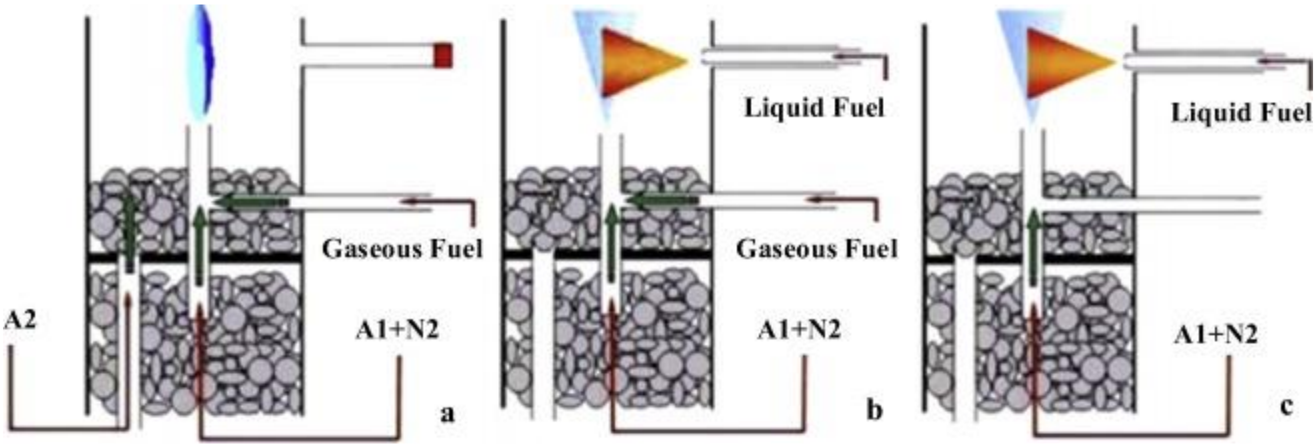


Figure 6: Reactants feeding system: (a) SN gas-fuel feed; (b) DN liquid- and gas-fuels feed; (c) DN liquid-fuel feed. A1: primary air; A2: secondary air [18].

Though the chemical reaction mechanism involved in such the combustion burner remains unknown and numerical or experimental approaches are required to reveal this, such work does corroborate its potential for the combustion applications with liquid fuel.

2.5 Colorless distributed combustion

From 2010 to 2016 [13–16], the research team from University of Maryland put forward a new concept called colourless distributed combustion (CDC), which is based on the principle of high temperature air combustion (HiTAC) [20].

It is a fact that the major challenge in the CDC (no visible flame signatures) research is about the design of burner for application to the combustors. Such design determines the effectiveness of the combustion process in the CDC mode, and hence controls the ignition time, temperature uniformity and pollutant emissions especially.

The research team compared the CDC with rich burn-quick quench-lean burn (RQL) combustion and other low emission combustion models, and CDC showed great potential to reduce NOx and CO emissions in addition to improved pattern factor and low noise. Many different combustor models (as shown in Figure 7) were designed to prove that the mixing between the combustion air and product gases to form hot and diluted oxidant prior to its mixing with the fuel is critical.

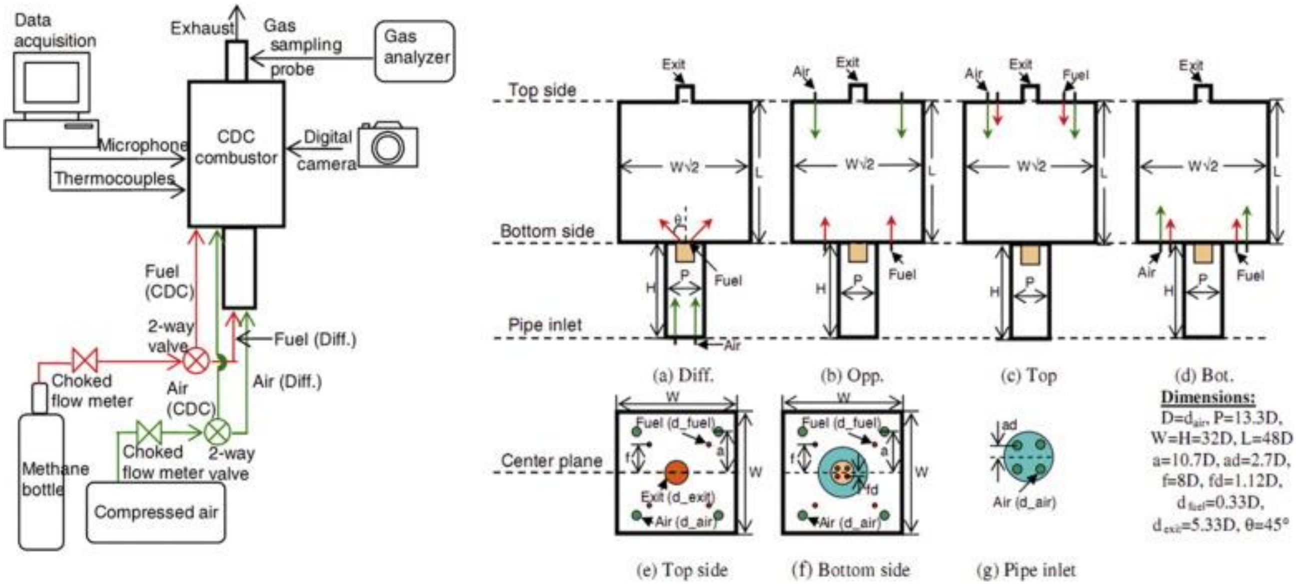


Figure 7: Line Diagram of CDC test facility and the different flow field configurations [20].

Experimental and numerical methods were used to find out that the flow field configurations and significant recirculation of gases had great effect on fuel jet characteristics as well as the fuel/air mixing. Distributed reaction zone, better thermal filed uniformity and lower NO (7 ppm, phi = 0.7) and CO (20 ppm, phi = 0.7) emissions were observed for non-premixed model [18–19]. In 2012 [19], they achieved ultra-low NOx emissions for both the novel premixed (1 ppm) and non-premixed (4 ppm), low CO emission (30 ppm at phi = 0.5) and very low pressure fluctuations (<0.025%) characteristics of CDC, when Tair = 600 K (see Figure 8).

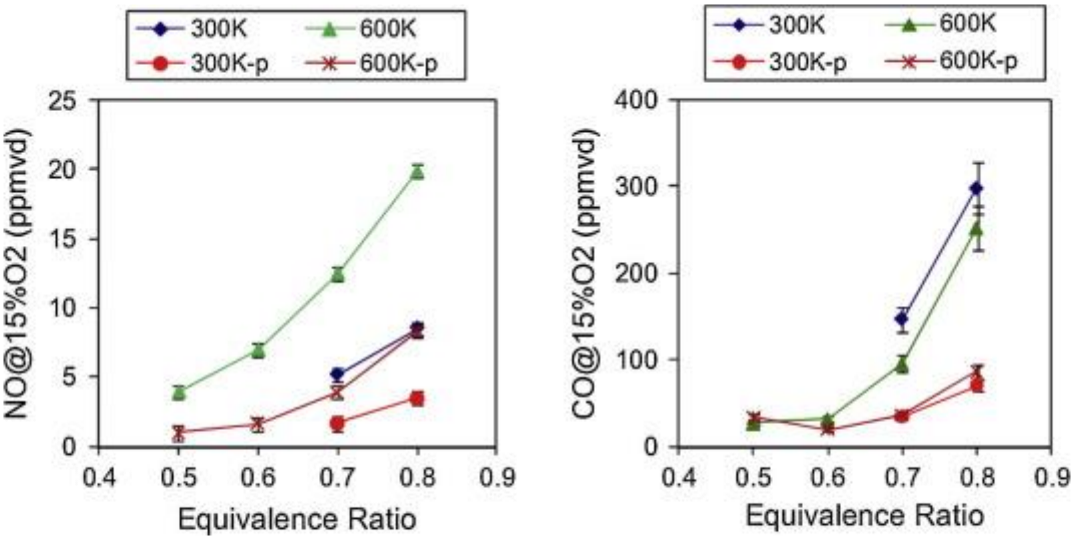


Figure 8: NO and CO emissions in non-premixed and premixed conditions (p denotes premixed) for the CDC combustor [19].

Furthermore, in Refs. [20,21], results were represented for both non-swirling ‘‘linear’’ flow and swirling flow. Swirling flow exhibited high velocity region at the core of the combustor to further promote mixing and entrainment of reactive species. All of these research aspects will provide valuable information for significant improvements of gas turbine combustors performance.

2.6 Model combustor

In 2010, researchers from Chinese Academy of Sciences focused on the dynamic characteristics of a model combustor [19–20]. The model combustor is a can-type reverse flow combustor (Figure 9) with two parts: head and chamber. The head of the combustor comprises the air and the fuel distribution units. All the air is injected into the chamber by co-flow injection through the twelve main nozzles. There is a concave recirculation structure at the head of combustion chamber in which the burned gas recirculates and mixes with fresh reactants. The positional relationship between the nozzles and the concave structure raises the mixture's temperature above the fuel self-ignition temperature, and dilutes the air to reduce the concentration of O_2, thereby achieving the combustion. Additionally, there is a pilot nozzle fixed in the center of the concave recirculation structure, which is designed for ignition and maintaining combustion in case that the equivalence ratio is low. Therefore, in the combustor's mixed mode, the fuel is partially premixed. The pure methane and nitrogen-diluted methane (volume ratio of CH_4:N_2 = 1.0) were used as the main fuel, and propane was used for the pilot.

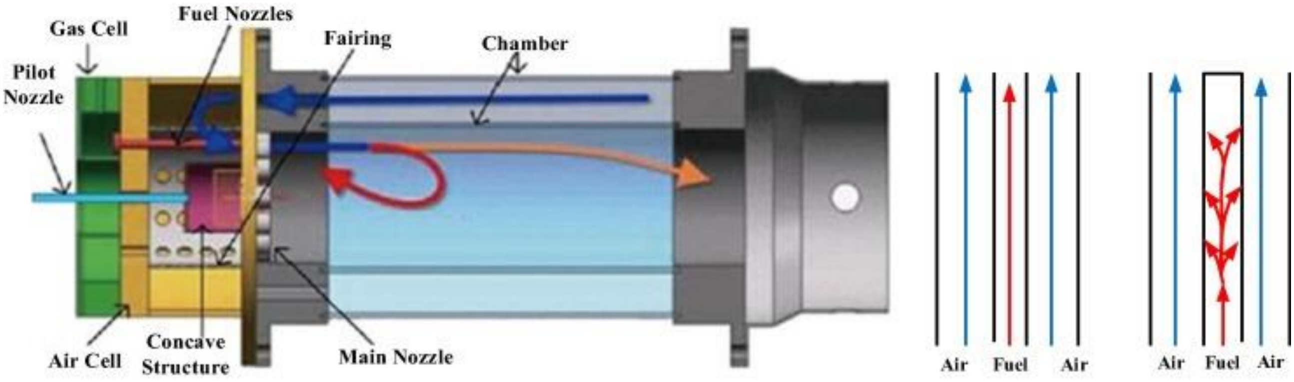


Figure 9: Cross-section view of the combustion model combustor and fuel nozzle [18].

In this model combustor, there are three working modes (see Figure 10). These are Pilot-only mode, mixed mode (the pilot and main nozzles work together), and the mode. The pilot nozzle is shut off, while the main nozzles continue to supply fuel, attaining the combustion.

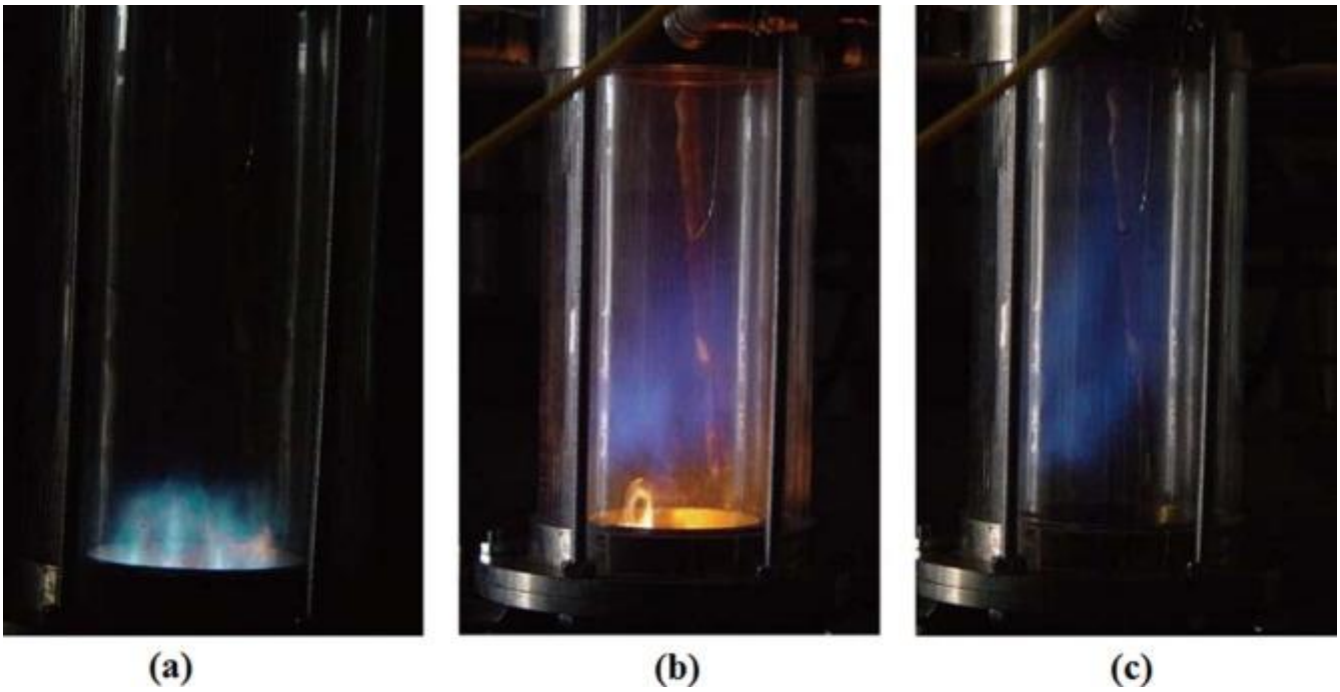


Figure 10: The combustor ignition sequence (a) Mode I: pilot nozzle only; (b) Mode II: pilot and main nozzles; (c) Mode III: main nozzles only [19,20].

The highlight of the research is the use of the dynamic pressure sensors to detect the dynamic pressure signal. An autoregressive (AR) model was used to estimate the power spectrum. Furthermore, there was no dominant oscillation amplitude in the combustion. The combustion mode showed lower combustion noise and no thermal-acoustic oscillation problems while achieving ultra-low NOx and CO emissions. However, when the pilot flame coexisted with the main combustion flame, instability was excited at certain equivalence ratios. The experimental method is very helpful to identify the transformation from the conventional combustion to the mode.

2.7 Thermoelectric generators

Thermoelectric generators (TEGs) are a predecessor in various direct heat to electricity conversion systems. TEGs were one of the first devices developed for direct conversion of heat to electricity and are still used today. They utilize the thermo-electric effect which includes the Seebeck effect (discovered by Thomas Johann Seebeck in 1821), the Peltier effect (discovered by Jean Charles Athanase Peltier in 1834), and Thomson effect (discovered by William Thomson also known as Lord Kelvin in 1851). The Thomson effect describes how a gradient in current density caused by the dissimilarity in temperature at one end of a conducting material and the other will cause electricity to flow from one end of the material to the another.

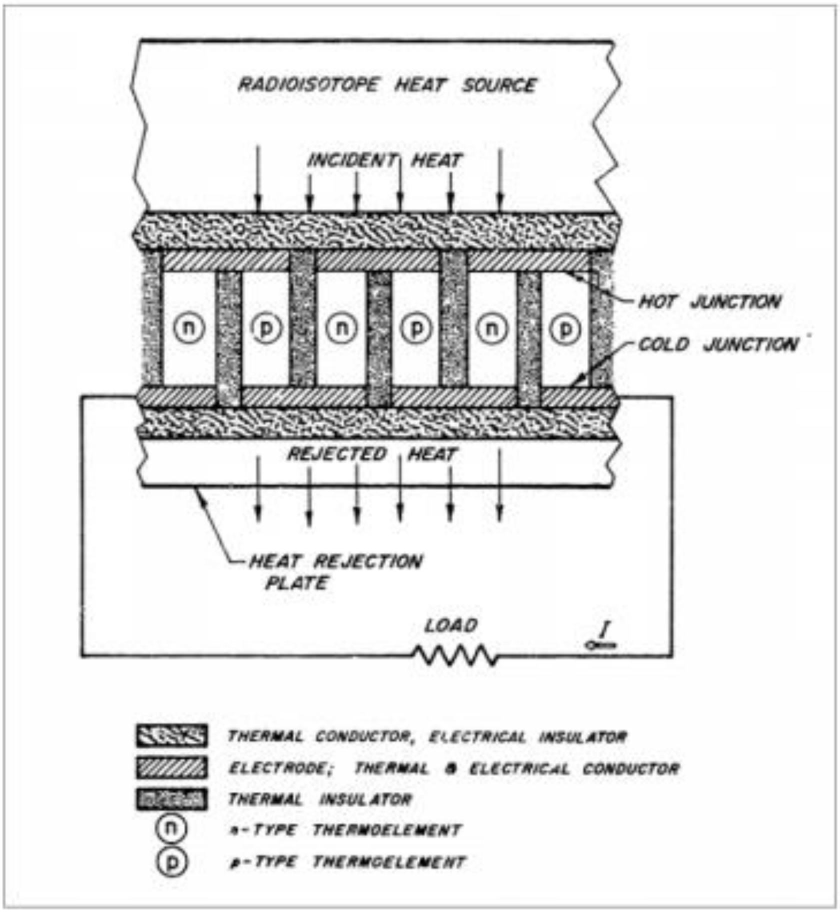


Figure 11: Basic TEG design

Unfortunately, TEGs are generally not very efficient particularly with a small temperature difference, ΔT across the device. Though theoretical efficiency for a given device can be complex to calculate, experimental results for a modern commercial TEG, obtained by O'Halloran and Rodriguez, showed a maximum efficiency of only 2.22% with an average ΔT = 68.1 °C. They later stated that other research has shown TEGs can potentially achieve an efficiency of 10% with a ΔT = 500 °C but even this efficiency is a lower than the modern PVs and would require remarkable engineering to maintain the required temperature difference.

The stoichiometric *mass* based air/fuel ratio for $C_\alpha H_\beta$ fuel is:

$$(A/F)_s = \frac{m_{air}}{m_{fuel}} = \frac{\left(\sum n_i \overline{M}_i\right)_{air}}{\left(\sum n_i \overline{M}_i\right)_{fuel}} = \frac{\left(\alpha + \frac{\beta}{4}\right)\overline{M}_{O_2} + 3.76\left(\alpha + \frac{\beta}{4}\right)\overline{M}_{N_2}}{\alpha \overline{M}_C + \beta \overline{M}_H}$$

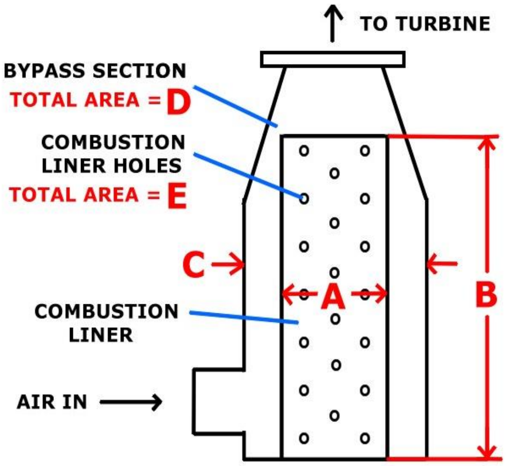


Figure 12: Sample Combustor

2.8 Performances of the thermoelectric system

The thermal characteristics of the burner are affected by the limits of combustion which is theoretically bounded by the leanest and the richest fuel-air mixtures. These limits are also known as blow-out and lift-off respectively. The operating envelope of the fuel-air mixtures within these limits will have crucial effect on the temperature and the emissions of the burned gases. The dependency on the fuel-air mixtures explains the necessity of quantifying the combustion performance of the burner over wide range of fuel-air equivalence ratio. Lean burning is commonly associated with greater fuel economy and reduced emissions of carbon monoxide (CO) and nitrogen oxides (NO_2). The generated flame stabilized from a lean fuel-air equivalence ratio of 0.80 to a rich fuel-air equivalence ratio of 1.25. A uniform wall temperature profiles was observed and upper temperature limits could be dramatically reduced which is suitable for a TE power generator. Since the fuel-air equivalence ratio is directly dependent on the amount of fuel and air flows. The resulting heat of combustion will vary accordingly.

The power-temperature dependence is apparently influenced by the load of the system and the power-temperature profile could reach a saturation value when the temperature difference reaches certain limit. The fossil fuels are readily available, their combustion is commonly associated with various emissions products such as carbon monoxide (CO) and nitrogen oxides (NO_2). Given the emissions of CO and NO_2 are pernicious to the environment, reducing these pollutants to a manageable level is crucial in any combustion related devices. In an exhaust gas generation from internal combustion engines where TE applications was reported, the focused was solely on power generation without elaborating the emissions profiles. In any combustion system, CO emission is commonly used to gauge the completeness of combustion. Its quantitative measure reflects the effectiveness of a combustion process towards converting into a much more benign emission of CO_2. Leaning the mixture (ϕ <1) is theoretically favourable given the inclination towards achieving a complete combustion. On the contrary, enriching the fuel-air mixtures beyond stoichiometric appears to affect substantially the amount of CO. Stoichiometric fuel-air mixtures would also result in decreased amount of CO since temperatures generated are higher and therefore enabling complete conversion to CO_2. To date, the effects of fuel-air equivalence ratio on the behaviour of CO emissions have not been comprehensively evaluated.

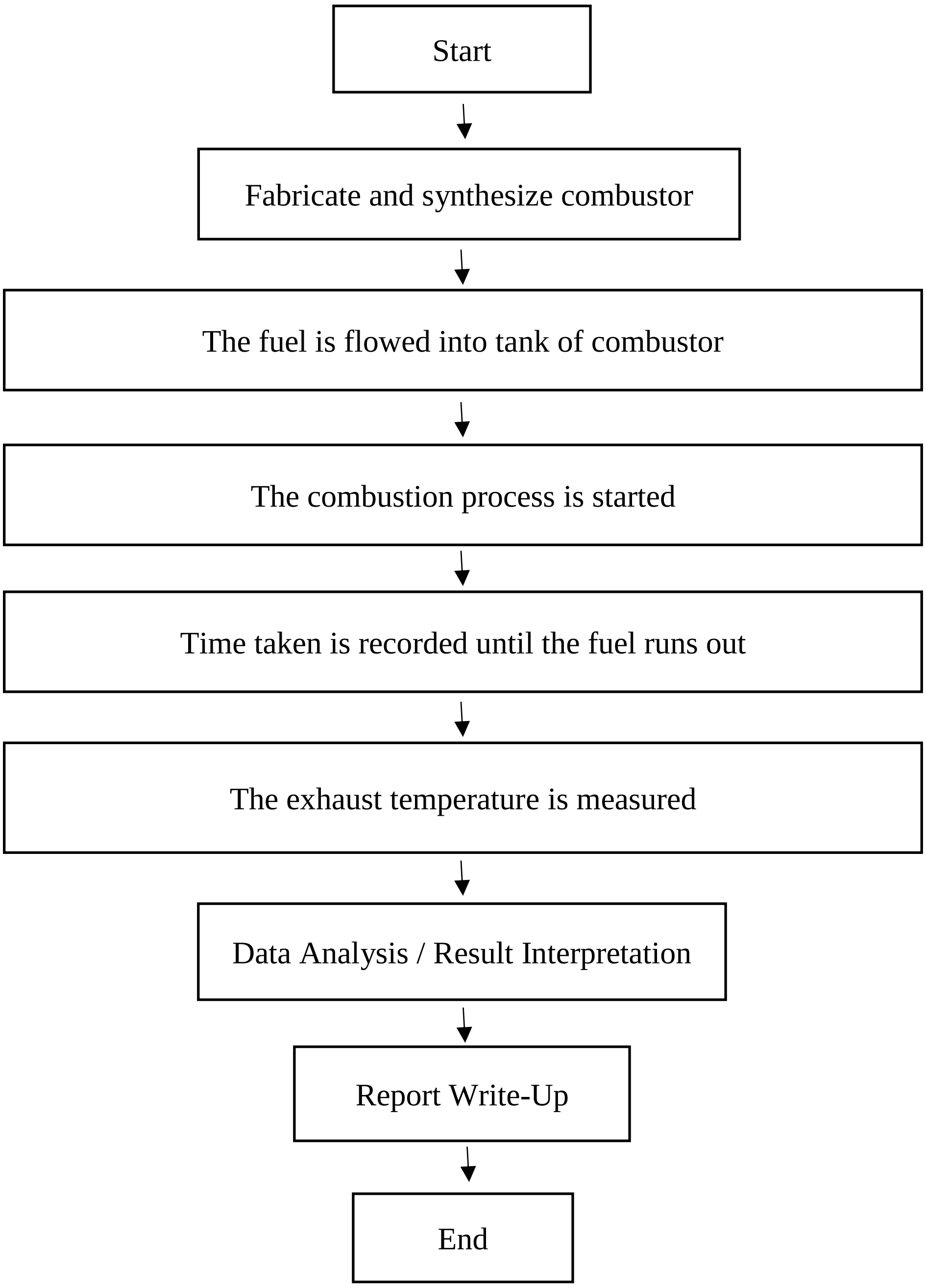
2.9 Porous media applications in thermoelectric generators

The porous medium arrangement was slightly expansive and complicated. A low voltage output was recorded for a temperature gradient in excess of 500 °C. Neither voltage nor power output was discussed in this study. Realizing that operating a porous medium burner at lean mixtures impacted great importance, the reciprocating flows of combustion at fuel−air equivalence ratio between 0.465 and 0.588. Ultra-lean mixture was also tested in their later work but this analytical work was strictly limited to the thermal efficiency and power output only. The looming need for heat and electric cogeneration was further attempted using a ceramic porous alumina to enhance the heat transfer in the porous solid.

The micro-power output of 181 mW was achieved at a lean fuel−air equivalence ratio 0.589 and a maximum power output of 1.4 W was attained when the porous burner was operated at a rich fuel−air equivalence ratio of 1.3. At this juncture, it is difficult to say if the output−equivalence ratio relationship is linear. Based on the selected reviews presented here, it is clear that previous researches were either concentrated on lean or rich mixture of fuel-air equivalence ratio. In addition, there seems to be negligible effort to cover both regions of rich and lean mixtures in a single study.

CHAPTER 3 METHODOLOGY

3.1 Experiment flow chart process



The kerosene fuel is flowed into the tank of combustor so that it can burn in the combustor. Time taken has been recorded until the fuel inside the combustor is runs out. The temperature that exhausted also recorded by the thermocouple. The data recorded from the experiment is tabulated in a table. It can achieve the project goals of developing a combustor for a combustion system.

Figure 13: The burning process of combustor

3.2 Procedures of the experiment

1. First, get all things together (combustor, stand, thermoelectric, lighter, paper, and fuel).

Figure 14: Combustor and stand

Figure 15: Thermoelectric, lighter, paper, and fuel

2. Then, pour the fuel to the inner chamber of combustor.

3. Burn the fuel.

4. Wait until the combustion process occurs.

5. Put stand covering on top of the combustor as in the picture.

Figure 16: Stand on top of the combustor

6. Put thermoelectric that attached with its fan on top of the chamber as in the picture.

Figure 17: Thermoelectric on top of the stand

7. Connect with two wires, black (negative) and red (positive) to the multimeter.

8. Get initial reading of the voltmeter and current to the TE.

9. Then, get 10 readings for the combustion process.

10. Find power according to the formula P = V x I.

11. Tabulated in the table.

12. Plot the graph.

    a) V against I

    b) P against I

    c) P against V

Manipulated Variable is temperature. We change the temperatures in the experiment by using thermocouple.

3.3 Combustion calculation

Most liquid fuels are mixtures of many different Hydrocarbons. Common examples are Gasoline, Kerosene, Diesel oil etc. Commonly a liquid fuel is treated as a single hydrocarbon with an empirical formula CxHy even though it is a mixture of several hydro carbons. The reaction of liquid fuels with oxygen liberate heat and the heat is used for various purposes. The main combustion products of burning of fuels are carbon dioxide and water. Combustion is the reaction of a fuel substance with air or pure oxygen to form combustion products. The combustion process is always exothermic and it liberates heat.

The combustion reaction may be written as:

$$Fuel + O_2 \rightarrow Products + Heat$$

Carbon monoxide may be formed for incomplete combustion, which is further reacted to form carbon dioxide. The minimum amount of air which supplies the required amount of oxygen for complete combustion of a fuel is called the stoichiometric or theoretical air. The amount of air in excess of the stoichiometric air is called excess air. It is usually expressed in